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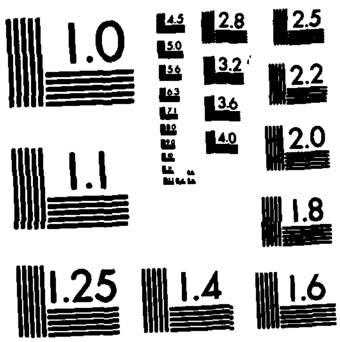

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Monterey, California

THESIS

OPTIMIZATION OF THREE DIMENSIONAL COMBINED TRUSS/FRAME STRUCTURES

by

Gregory L. Bender

October 1982

Thesis Advisor: G.N. Vanderplaats

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The finite element code may be used for analysis only, or may be coupled to an optimizer of the user's choice. The

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Flexibility is provided for expansion to other than tubular frame elements, and provisions are made for the future growth to panel and other types of structural elements.

Documentation is provided to facilitate use of the code. A User's manual is presented with examples and results. An explanation of how this code may be coupled to an optimizer is also provided.

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Optimization of Three Dimensional Combined Truss/Frame Structures

by

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Submitted in partial fulfillment of the requirements for the degrees of

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AND

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ABSTRACT

A finite element code is developed for analysis and design of three dimensional truss and frame structures. Structures are designed for minimum weight subject to constraints on: member stresses, Euler buckling, shell buckling, joint displacements and system natural frequencies. Structures are optimized with respect to member size and structure configuration.

The finite element code may be used for analysis only, or may be coupled to an optimizer of the user's choice. The displacement method is used for static analysis, and structure natural frequencies are calculated via the subspace iteration method.

Flexibility is provided for expansion to other than tubular frame elements, and provisions are made for the future growth to panel and other types of structural elements.

Documentation is provided to facilitate use of the code. A User's manual is presented with examples and results. An explanation of how this code may be coupled to an optimizer is also provided.

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I have been fortunate enough to receive a great deal of assistance, guidance, and encouragement during the course of the year I have spent doing my research and developing my design code.

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I want to express my most heartfelt appreciation to Professor Gary Vanderplaats for his guidance, his encouragement, his time, and his patience during the course of this project. His ability to cut to the heart of the problem made my task ever so much easier. I cannot thank him too much.

Finally to my loving wife and partner in this endeavor, Alice, words are inadequate to express my appreciation for the support you have provided during the past 27 months here at the Naval Postgraduate School.

I. INTRODUCTION

The task of the Engineer is to provide the best solution to the customer's problem. Usually the "best" solution is the one that does the job with an adequate margin of safety, is aesthetically pleasing, and is economically feasible. The solution may be reached through various means, but efficient use of design tools, as well as efficient use of materials is important since both add to the overall cost of the product. Design optimization is one method that can be used to maximize the efficiency of a structure by minimizing its weight and, presumably, cost.

Optimization of structures has had continuing changes since its development in the early 1960's with an active area of research being elastic structures. The main goal is to design structural systems that efficiently perform specified purposes. Since most physical structures can be modeled by the finite element method, a computer program can be written to perform the necessary calculations to solve the problem.

The purpose of this research was to develop a finite element code that could be used to analyze a combined truss/frame structure and could be easily coupled to an optimizer; thus providing a useful tool for designing such structures

as, for example, ships' masts. This code expands the previous work by Fitzgerald [Ref. 1] on truss structures to the more general six degree-of-freedom truss/frame case.

The design problem considered in this study is the optimization of three-dimensional statically indeterminant combined truss-frame structures under varying load conditions and subject to a variety of constraints. The objective is to minimize the weight of the structure where the design variables are member sizes and joint coordinates. Constraints include: maximum normal stress; maximum joint displacements; minimum structure natural frequencies; Euler buckling; and in the case of the tubular frame elements, local or shell buckling.

In the present code, all gradient information is calculated by the finite difference method. Modification of the code to permit calculation of gradients analytically has been identified as a necessary future extension.

This document describes the use and capabilities of the finite element computer code to be coupled to an optimizer. The user's manual presented in Chapter V contains a simple design example in which the program is coupled to the CONMIN optimization code [Ref. 2]. Additionally, guidelines for coupling the code to an optimizer of the user's choice are presented.

Several examples demonstrating the program under a variety of conditions are presented. Conclusions and recommendations for future work are given.

II. ANALYSIS

A. INTRODUCTION

When the finite element method of analysis is used to design optimization, two objectives must be kept in mind. First, the number of analyses for the structure should be kept to a minimum. Second, the amount of gradient information required during the design process should be minimized to shorten run times and minimize computer storage requirements.

B. STATIC ANALYSIS

Initial formulation of the problem must include approximate member areas in the case of truss elements, and for frame elements, characteristic dimensions (for tubular members: mean diameter and wall thickness); material properties (which may be different for each member); a set or sets of external loads; any non-structural attached masses; and specified joint support conditions.

The analysis for the stresses and deflections at the joints must satisfy the conditions of equilibrium of forces at the nodes and geometric conditions of compatibility of deformation. In this analysis the structure is assumed to behave in a linearly elastic fashion. The weight of an individual member is not inherently included as part of the

specified load conditions; but, as an option, half of the weight of each member may be applied at the member's end-points as an additional load in the negative Y-direction.

For this analysis, the following assumptions are made: truss and frame members are treated as discrete entities; truss elements have three translational degrees of freedom at each node and are treated as pin-connected; frame elements have three translational and three rotational degrees of freedom at each node and are treated as fixed-fixed beams; and loads and reactions are applied at the joints as shown in Figure 2.1.

The Displacement (Stiffness) method for finite element analysis [Ref. 3] is utilized where

$$\underset{\approx}{K}\underset{\sim}{u} = \underset{\sim}{F} \tag{3.1}$$

and where $\underset{\approx}{K}$ is the global stiffness matrix, $\underset{\sim}{F}$ is the vector or vectors of applied loads, and $\underset{\sim}{u}$ is the vector or vectors of displacements. The method used herein is an extension of that described by Felix and Vanderplaats [Ref. 4]. By applying the constitutive stress-displacement relationships, stresses in the elements may be recovered.

C. DYNAMIC ANALYSIS

When constraints on the system's natural frequencies are to be considered, the design process requires the solution of an eigenvalue problem. The sub-space iteration

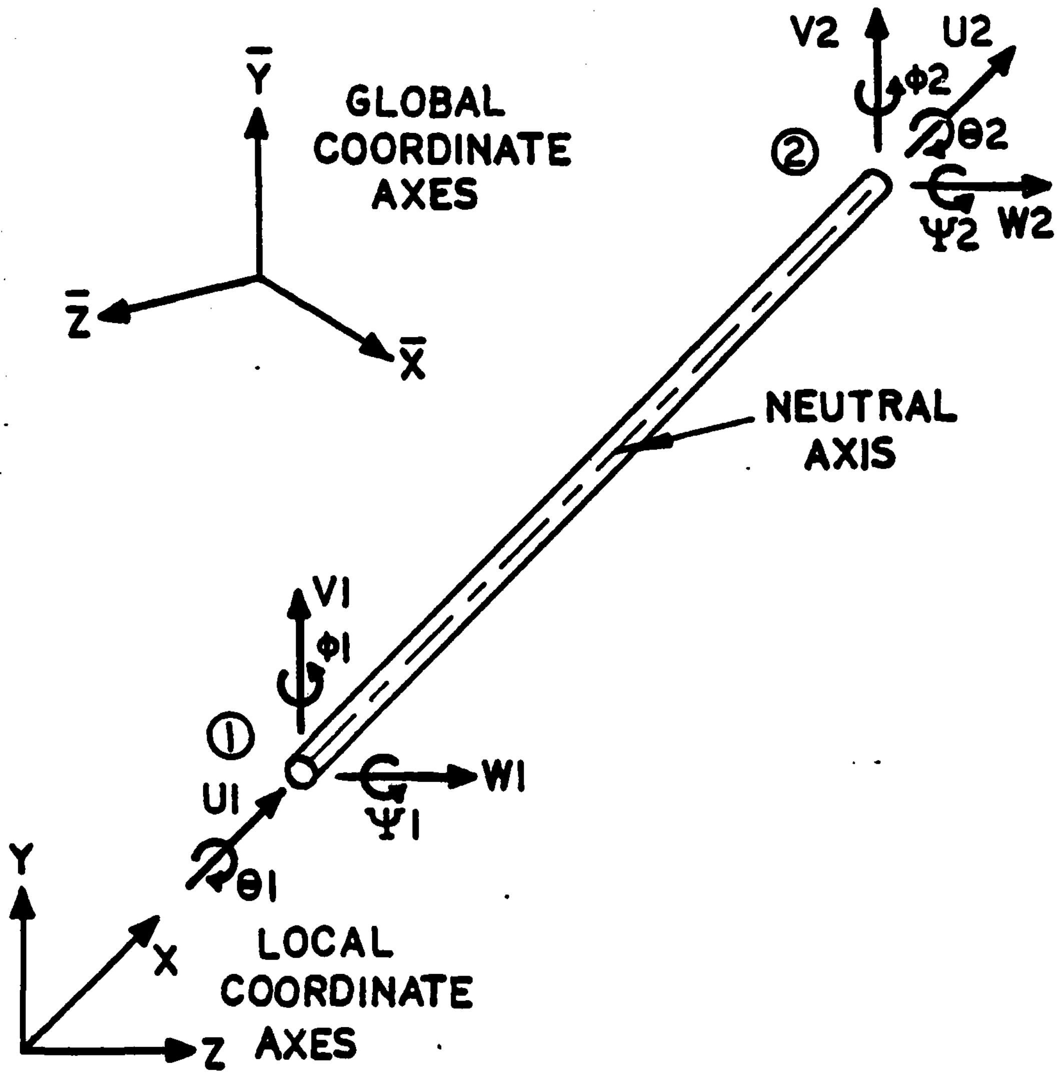

Figure 2.1 FORCE ORIENTATION CONVENTION FOR AN ELEMENT

method of Bathe and Wilson [Ref. 5] is used to solve for the desired number of lowest eigenvalues and the associated eigenvectors. This method is reasonably efficient for a small number of lowest frequencies for a large problem, and is well suited for re-analysis when small changes are made in the design.

D. GRADIENTS

Gradients are currently calculated with respect to member sizes and coordinates only by finite difference techniques. Inclusion of the capability to calculate gradients analytically is identified as a needed extension to this work.

III. OPTIMIZATION

A. INTRODUCTION

The primary objective of structural optimization is to design systems that efficiently perform specified purposes. Selection of a specific optimizing algorithm must take into account the following: 1) the structure should be analyzed as few times as possible; 2) the algorithm should minimize the amount of gradient information required; 3) the algorithm should provide reasonable assurance that an optimum or near-optimum design will be reached.

B. GENERAL FORMULATION

The general statement of inequality constrained minimization is as follows:

Minimize

$$F(\underset{\sim}{X}) \qquad (4.1)$$

Subject to:

$$G_j(\underset{\sim}{X}) \leq 0 \qquad j=1,m \qquad (4.2)$$

$$x_i^{\ell} \leq x_i \leq x_i^{u} \qquad i=1,n \qquad (4.3)$$

where $F(\underset{\sim}{X})$ is the objective function to be minimized. The functions $G_j(\underset{\sim}{X})$ are the set of inequality constraints to be met. The vector $\underset{\sim}{X}$ contains the design variables.

The inequality constraints, $G_j(\underset{\sim}{X}) \leq 0 \quad j=1,m$, must be satisfied for the design to be accepted as feasible. Side constraints, x_i^{ℓ} and x_i^u, are lower and upper bounds on the design variables. The objective function must be minimized as much as possible while still satisfying all inequality constraints. In the case that it is not possible to satisfy all constraints, the most nearly feasible solution must be found. Felix and Vanderplaats [Ref. 4] is an excellent source for the basic structural design formulation.

C. DESIGN VARIABLES

The vector $\underset{\sim}{X}$ contains the design variables; in this case, member characteristic dimensions for frame elements, cross-sectional areas for truss elements, and spacial coordinates of the joints. The user may elect to optimize the structure weight with respect to any combination of the above variables.

For truss elements, where normal stress is dependent only upon the magnitude of the cross-sectional area of an element and not the distribution of that area, it is sufficient to use the area as the design variable as long as the Euler buckling stress can be related to the cross-sectional area. For frame elements where stresses are dependent on area distribution, more flexibility is allowed by varying two characteristic dimensions and allowing the code to calculate the section properties from these.

In the case of tubular elements, the characteristic dimensions are mean diameter and wall thickness; from which area, bending and polar moments, and maximum radial dimensions are generated.

The optimum geometry problem requires that the joint coordinates be design variables. The x, y, and z coordinates of a joint are treated as separate design variables.

In many cases it is desirable to link a set of design variable together to preserve symmetry, limit the number of variables to be solved, or to limit the number of unique elements to be manufactured. The code has provisions for design variable linking by which two or more variables may be linked in equality or some fixed ratio.

D. OBJECTIVE FUNCTION

The objective function under consideration is weight

$$F(\underset{\sim}{X}) = \sum_{i=1}^{NE} \rho_i A_i L_i \tag{4.4}$$

where ρ_i is the weight density (in consistent units) of the material of the ith element, A_i is the cross-section area of the ith element, and L_i is the length of the ith element and NE is the number of elements in the structure.

E. CONSTRAINTS

This code is designed to accommodate constraints on maximum normal stress, Euler buckling, local or shell buckling,

maximum joint displacements, and minimum natural frequencies of the structure. All constraint values are normalized.

1. Stress:

For truss elements, maximum normal stress σ_M is calculated directly from the element tensile forces. For frame elements; tensile stress σ_A , maximum bending and shear stresses σ_B and σ_T are calculated. Maximum and minimum normal stresses are

$$\sigma_{max} = \text{max magnitude of } \frac{\sigma_A \pm \sqrt{(\sigma_A{}^2 + 4\sigma_T{}^2)}}{2} \tag{4.5}$$

$$\sigma_{min} = \text{min magnitude of } \frac{\sigma_A \pm \sqrt{(\sigma_A{}^2 + 4\sigma_T{}^2)}}{2} \tag{4.6}$$

The upper and lower bounds on stress may be different for each member, but are taken to be the same for every loading condition.

2. Local or Thin Shell Buckling

The stress at which local or thin shell buckling occurs is given by:

$$\sigma_{L_i} = \frac{0.4E_i}{D_{m_i} / t_i} \tag{4.7}$$

where the subscript i corresponds to the member number, E_i is Young's modulus, D_{m_i} is the element's mean diameter, and t_i is the element's wall thickness.

F. DESIGN VARIABLE BOUNDS

Side constraints are imposed on the design variables as:

$$CD_i^{\ell} \leq CD_i \leq CD_i^{u} \tag{4.8}$$

CD is the characteristic dimension and CD_i^{ℓ} and CD_i^{u} are the minimum and maximum allowable characteristic dimensions of the ith element, and are taken to be the same for all load cases. If, as is the case in a tubular element, geometry dictates that some relationship between the design variables cannot be exceeded, i.e., thickness cannot exceed the mean diameter, the user must arrange the bounds to preclude such an occurrence.

G. *OPTIMUM GEOMETRY*

Joint coordinates are treated as design variables with a separate design variable for each coordinate direction of a node. Coordinate design variables may also be linked.

IV. PROGRAM FEATURES

A. INTRODUCTION

Computer codes each have their own features and formats with which the user must become familiar if he is to use the code easily and efficiently. The SADX code developed in the course of this research has been designed with various options which are explained in this chapter. Chapter V contains a User's Manual with sample data for a typical problem that might be solved with this code: a truss-braced cantilever beam. This problem along with other numerical examples will be presented in detail with results in Chapter VI.

The SADX code was written to be used as a stand alone analysis program or as an analysis code that could be easily be coupled to an optimizer (of the user's choice) through simple modifications to the main driver program.

B. FEATURES

When the user supplies member areas, section types, characteristic dimensions, material data, connectivities and joint coordinates, along with a set of program control parameters; the analysis mode will calculate the weight of the structure. The addition of one or more sets of loading parameters will result in the calculation of resultant joint

displacements, member stresses, and/or forces for each load case along with the desired number of structure natural frequencies and modes. Design variables may be chosen as truss element areas, frame element characteristic dimensions, and joint coordinates. When coupled to an optimizer, the code will minimize the weight of the structure and print the final optimization information. The code is designed to be as simple to use as possible while retaining the flexibility for use on a variety of problems.

The code's modular construction allows the user to use frame element cross-sections other than tubular elements. This is done by reading in two characteristic dimensions for each frame element along with a section type identifier. Subroutine SADX85 is called to calculate the section properties, area, maximum radial dimensions, and bending and polar moments of inertia. The user may augment this subroutine to calculate section properties for whatever section type he may choose to work with.

Many computer codes require the definition of an auxiliary node to orient the principle axis of a non-axially symmetric element. In this code it is assumed that the element's local z-axis is parallel to the global x-z plane.

Pseudo-dynamic storage is used to allow storage of most data in one integer and one real array for more efficient use of storage.

Various print control options are available to tailor the printed output to match the user's desires.

Design variable linking is available to allow elements and joints to be grouped to maintain symmetry, limit the number of independent design variables, or reduce the variety of member sizes generated.

Optimization may be performed with respect to member size, with respect to structure geometry, or with respect to both.

Structures may be comprised of truss elements, frame elements, or a mix of the two types.

Structures may be optimized for multiple load cases with constraints imposed upon any combination of maximum normal stress, maximum joint displacements and rotations, Euler and local buckling, and a specified number of minimum natural frequencies in free vibration. Separate displacement constraints may be imposed for each load case. Both consistent and lumped mass options are coded. Either forces or stresses or both can be output. The user may decide whether to include the structure's weight and the fixed masses as loads applied to the structure.

C. EXAMPLE

The following example of the truss-braced cantilever beam presented in Tables (I-V) demonstrates some of the options available in the code.

TABLE I

TRUSS-BRACED CANTILEVER BEAM: INPUT CONTROL PARAMETERS

INPUT PARAMETERS FOR STRUCTURAL ANALYSIS AND DESIGN ROUTINE, "SADX"

TRUSS-BRACED CANTILEVER BEAM: EXAMPLE 1

CONTROL PARAMETERS

TOTAL NUMBER OF ELEMENTS,	NE=	4
TOTAL NUMBER OF BAR ELEMENTS,	NEB=	2
TOTAL NUMBER OF FRAME ELEMENTS,	NEF=	2
TOTAL NUMBER OF JOINTS,	NJ=	5
JOINT MAXIMUM DEGREES OF FREEDOM,	JCM=	6
JOINT CONSTRAINT VARIABLE,	NCJ=	3
NUMBER OF MATERIAL TYPES,	NMT=	2
NUMBER OF LOAD CONDITIONS,	NLC=	2
NUMBER OF EIGENVALUES,	NEIG=	1
NO. OF EIGENVALUES CALCULATED,	NEIG1=	2
NUMBER OF FIXED MASSES,	NFMASS=	1
EULER BUCKLING CONSTRAINT ID,	NEUBC=	1
LOCAL BUCKLING CONSTRAINT ID,	LBUCK=	1
NO. OF DISPL. CONSTRAINTS,	NDSPLC=	2
NO. OF FREQ. CONSTRAINTS,	NFREQ=	1
LUMPED MASS OPTION,	LMASS=	0
FORCE/STRESS PRINT OPTION,	NSTRES=	2
OPTIMUM SIZE/BOTH/GEOM OPTION	IDVCLC=	2
STRUCTURE WEIGHT AS LOADS OPTION	NSTW=	1
FIXED MASSES AS LOADS OPTION	NFMW=	1

ACCELERATION DUE TO GRAVITY, GRAV = 0.38640E+03
EIGENVALUE CONVERGENCE TOLERANCE, EPSEIG = 0.10000E-03

TABLE II

EXAMPLE 1: JOINT COORDINATE AND MEMBER INPUT DATA

JOINT COORDINATES

JOINT	X	Y	Z
1	0.0	0.0	0.0
2	0.10000E+03	0.0	0.0
3	0.20000E+03	0.0	0.0
4	0.0	0.15000E+03	0.0
5	0.0	0.0	0.50000E+02

COORDINATE DESIGN VARIABLES

JOINT	DESIGN VARIABLE X	Y	Z	MULTIPLIER X	Y	Z
1	0	0	0	0.0	0.0	0.0
2	0	0	0	0.0	0.0	0.0
3	0	0	0	0.0	0.0	0.0
4	0	1	0	0.1000E+01	0.1000E+01	0.1000E+01
5	0	0	2	0.1000E+01	0.1000E+01	0.1000E+01

ELEMENT INFORMATION FOR BAR ELEMENTS

ELEMENT-JOINT RELATIONSHIPS

LNO	NODE1	NODE2	MATL	DVAR1	AREA	LENGTH
1	2	4	1	1	0.3000E+01	0.1803E+03
2	2	5	1	2	0.3000E+01	0.1118E+03

ELEMENT INFORMATION FOR FRAME ELEMENTS

ELEMENT-JOINT RELATIONSHIPS ELEMENT PROPERTIES

ELEMENT NUMBER 3

NODE1	NODE2	MATL	1ST DESVAR	2ND DESVAR
1	2	2	3	4

AREA	LENGTH	Z-MOMENT	Y-MOMENT	ZMAX	YMAX
0.157E+02	0.100E+03	0.511E+02	0.511E+02	0.300E+01	0.300E+1

ELEMENT NUMBER 4

NODE1	NODE2	MATL	1ST DESVAR	2ND DESVAR
2	3	2	3	5

AREA	LENGTH	Z-MOMENT	Y-MOMENT	ZMAX	YMAX
0.157E+02	0.100E+03	0.511E+02	0.511E+02	0.300E+01	0.300E+1

TABLE III

EXAMPLE 1: SAMPLE DISPLACEMENT AND FORCE/STRESS OUTPUT

```
NO. OF BAR ELEMENTS =    2
   LMC  LOAD COND  TENSILE FORCE IN X  MAX STRESS
    1       1         -0.7307E+04      -0.6628E+03
    1       2          0.1544E+04       0.4449E+03
   LMC  LOAD COND  TENSILE FORCE IN X  MAX STRESS
    2       1          0.7428E+04       0.8740E+03
    2       2         -0.3413E+05      -0.4016E+04
NO. OF FRAME ELEMENTS =    2

ELEMENT  LOAD COND  NODE  TENSILE FORCE  SHEAR FORCE   SHEAR FORCE   TORSION MOMENT  BENDING MOMENT  BENDING MOMENT   MAX
                          IN X DIREX     IN Y DIREX    IN Z DIREX    ABOUT X AXIS    ABOUT Y AXIS    ABOUT Z AXIS     STRESS

   3        1       LOW   -0.1757E+04    0.1066E+04   -0.3395E+01    0.0             0.3395E+03      0.3513E+05   -0.9632E+04
   3        1       HIGH   0.1757E+04   -0.1066E+04    0.3395E+01    0.0            -0.9766E-03      0.7145E+05    0.1903E+05

   3        2       LOW    0.6647E+04   -0.4187E+03   -0.1482E+04    0.0             0.4816E+05     -0.1332E+05    0.1647E+05
   3        2       HIGH  -0.6647E+04    0.4187E+03    0.1482E+04    0.0             0.1000E+06     -0.2835E+05   -0.2790E+05
ELEMENT  LOAD COND  NODE  TENSILE FORCE  SHEAR FORCE   SHEAR FORCE   TORSION MOMENT  BENDING MOMENT  BENDING MOMENT   MAX
                          IN X DIREX     IN Y DIREX    IN Z DIREX    ABOUT X AXIS    ABOUT Y AXIS    ABOUT Z AXIS     STRESS

   4        1       LOW   -0.4883E-03   -0.7145E+03   -0.4766E-05    0.0             0.1379E-03     -0.7145E+05   -0.2572E+05
   4        1       HIGH   0.4883E-03    0.7145E+03    0.4766E-05    0.0             0.7324E-03      0.6250E-01    0.2271E-01

   4        2       LOW    0.3906E-02    0.2859E+03    0.1000E+04    0.0            -0.1000E+06      0.2859E+05    0.3600E+05
   4        2       HIGH  -0.3906E-02   -0.2859E+03   -0.1000E+04    0.0            -0.1879E-00     -0.6250E-01   -0.6919E-01
EIGENVALUES AND EIGENVECTORS

MODE NUMBER    1
FREQUENCY  =  0.4188E+02 CPS
              0.2631E+03 RPS
EIGENVALUE =  0.6922CE+05
EIGENVECTOR   DEGREE OF FREEDOM
JOINT           1               2               3
   1        0.0             0.0             0.0
   2        0.0             0.0             0.0
   3       -0.23419E-01    -0.37585E-01    -0.74507E-01
   4       -0.50711E-01    -0.10745E-01     0.1583CE-03
   5       -0.23435E-01    -0.17155E-01     0.10000E+01


LOAD CONDITION     1

DISPLACEMENTS       DEGREE OF FREEDOM
JNT   X-DISPL        Y-DISPL        Z-DISPL       ROT ABT X    ROT ABT Y      ROT ABT Z      T ABT Z
 1    0.0            0.0            0.0           0.0          0.0            0.0            .0
 2   -0.105E-02     -0.275E-02     -0.137E-03     0.0          0.206E-05     -0.567E-04      .56646E-04
 3   -0.105E-02     -0.105E-01     -0.343E-03     0.0          0.206E-05     -0.875E-04      .87481E-04
 4    0.0            0.0            0.0           0.0          0.0            0.0            .0
 5    0.0            0.0            0.0           0.0          0.0            0.0            .0
LOAD CONDITION     2

DISPLACEMENTS       DEGREE OF FREEDOM
JNT   X-DISPL        Y-DISPL        Z-DISPL       ROT ABT X    ROT ABT Y      ROT ABT Z      T ABT Z
 1    0.0            0.0            0.0           0.0          0.0            0.0            .0
 2   -0.226E-03     -0.371E-02     -0.187E-02     0.0          0.416E-04     -0.847E-04      .84689E-04
 3   -0.226E-03     -0.161E-01     -0.784E-02     0.0          0.688E-04     -0.143E-03      .14269E-03
 4    0.0            0.0            0.0           0.0          0.0            0.0            .0
 5    0.0            0.0            0.0           0.0          0.0            0.0            .0
```

TABLE IV

EXAMPLE 1: SAMPLE CONSTRAINT OUTPUT INFORMATION

```
DISPLACEMENT CONSTRAINTS START AT NUMBER  2 AND STOP AT NUMBER  5

TRUSS ELEMENT STRESS CONSTRAINTS
      START AT NUMBER  6 AND STOP AT NUMBER 17

FRAME ELEMENT STRESS CONSTRAINTS
      START AT NUMBER 18 AND STOP AT NUMBER 41

THE NUMBER OF CONSTRAINTS NCTOT =    41

 1) -.408882E+02  -.161055E+01  -.389445E+00  -.258895E+00
 5) -.174111E+01  -.981588E+00  -.101841E+01  -.943857E+00
 9) -.101236E+01  -.987640E+00  -.103769E+01  -.102428E+01
13) -.975722E+00  -.102139E+01  -.888444E+00  -.111156E+01
17) -.901716E+00  -.126755E+01  -.732450E+00  -.152875E+01
21) -.471251E+00  -.118559E+01  -.972695E+00  -.597988E+00
25) -.140201E+01  -.225014E+00  -.177499E+01  -.127432E+01
29) -.959641E+00  -.171444E+01  -.285557E+00  -.100000E+01
33) -.999999E+00  -.123411E+01  -.965558E+00  -.581741E-04
37) -.199994E+01  -.999998E+00  -.100000E+01  -.132766E+01
41) -.951795E+00
```

TABLE V

EXAMPLE 1: FINAL OPTIMIZATION INFORMATION

```
FINAL OPTIPIZATICN INFCRMATION

 OBJ =    C.5E75C7E+C3

 DECISION VARIABLES (X-VECTOR)
 1) C.348C(E+01  0.84992E+01  0.48389E+01  0.21898E+00  0.15576E+00
 7) C.45432E+02

 CCNSTRAINT VALUES (G-VECTOR)
 1)-C.40888E+02 -0.161C6E+01 -0.38945E+00 -0.25889E+00 -0.17411E+01
 7)-C.10184E+01 -0.94386E+00 -0.10124E+01 -0.98764E+00 -0.10377E+01
13)-C.97572E+00 -0.10214E+01 -0.E8844E+C0 -0.11116E+01 -0.90172E+00
19)-C.73245E+00 -0.15287E+C1 -0.47125E+0C -0.11856E+C1 -0.97270E+CC
25)-C.1402CE+01 -0.22501E+00 -0.17750E+01 -0.12743E+01 -0.95964E+00
31)-0.28556E+00 -0.100C0E+C1 -C.10000E+01 -0.12341E+01 -0.96556E+00
37)-C.19995E+01 -0.10000E+01 -0.10000E+01 -0.13277E+C1 -0.95180E+C0

 THERE ARE     1 ACTIVE CCNSTRAINTS
 CCNSTRAINT NUMBERS ARE
    36

 THERE ARE     0 VICLATED CONSTRAINTS

 THERE ARE     0 ACTIVE SIDE CONSTRAINTS

 TERPINATICN CRITERION
 ABS(OBJ(I)-CBJ(I-1)) LESS THAN DABFUN FCR 3 ITERATIONS

 NUMBER OF ITERATICNS =    12

 OBJECTIVE FUNCTION WAS EVALUATED            114   TIMES

 CCNSTRAINT FUNCTICNS WERE EVALUATED         114   TIMES

 THIS RUN REQUIRED  116  STRUCTURAL ANALYSES

 NUMBER OF SECCNCS REQUIRED FOR EXECUTION = 2.79

 WEIGHT OF STRUCTURE GIVEN AREAS & LENGTHS
 WEIGHT=      0.5E751E+C3

 TCTAL WEIGHT INCLUCING FIXED MASSES
 TCTAL WEIGHT=      C.83751E+03

 JCINT COCRDINATES
JCINT         X                 Y               Z
  1      0.0              0.0             0.0
  2      0.1C0C0E+C3      0.0             0.0
  3      0.2C0C0E+C3      0.0             0.0
  4      0.0              0.84259E+02     0.0
  5      0.C              0.0             0.45432E+02

 ELEMENT INFCRMATICN FOR BAR ELEMENTS

 ELEMENT-JCINT RELATIONSHIPS

ELEMENT  NODE 1  NOCE 2     AREA          LENGTH
   1       2       4     C.3481E+C1    0.1308E+03
   2       2       5     0.8499E+01    0.1098E+03

 ELEMENT INFORMATICN FOR FRAME ELEMENTS

 ELEMENT-JCINT RELATICNSHIPS

 LNC NCCE1 NCCE2   AREA       LENGTH      CHAR.DIM.1  CHAR.DIM.2
  3    1     2  0.3329E+01  0.1000E+03  0.4839E+01  0.2190E+00
  4    2     3  0.2366E+01  0.1000E+03  0.4839E+01  0.1558E+00
```

V. USER GUIDE

A. INTRODUCTION

In developing any computer code for engineering analysis, it is necessary to additionally develop concise, easily understood documentation. This SADX USER'S GUIDE is written to be easily understood by the user having only minimal knowledge of the FORTRAN language. The format follows that of the optimization code, COPES/CONMIN [Ref. 2].

This chapter is devoted to acquainting the user with the code and necessary input data.

B. DESIGN EXAMPLE

The simple example of a four-element combined truss/frame structure is used to demonstrate some of the features of the SADX program.

The structure is shown in Figure 5.1, and consists of two tubular frame elements along the x-axis with two truss braces to the y and z axes from the joint between the frame elements. A non-structural fixed mass is attached at the outboard end of the second frame element where two loads are applied.

C. SADX DATA

The SADX program reads data from unit 5 and writes output on unit 6. Units 30 and 40 are used as scratch files.

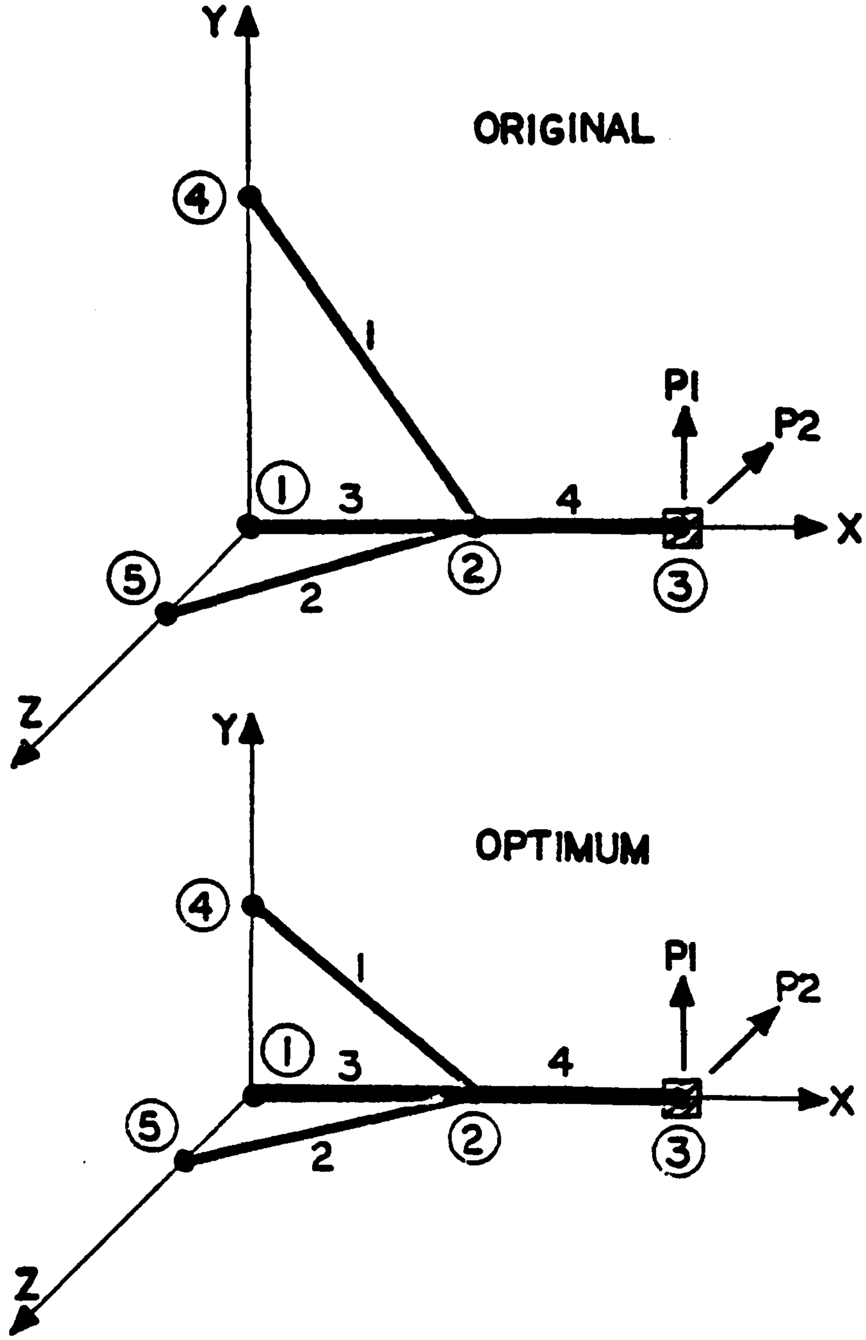

Figure 5.1 TRUSS-BRACED CANTILEVER BEAM

The scratch file numbers may be changed by changing two cards at the beginning of subroutine SADX01. The SADX program has the capability to read unformatted data. The following sections define the data which is required by SADX. The data is segmented into "BLOCKS" for convenience.

SADX data begins with a TITLE card and ends with a END card. Comment cards may be inserted anywhere in the SADX data stack prior to the END card, and are identified by a dollar sign ($) in column 1. Data may be of either the "I10" or "F10.0" type or may be free-format separated by commas with no imbedded blanks. Lines of formatted and unformatted data may be intermixed.

1. Formatted Data

Formats are of "I10" and "F10.0" type. "I" formats must be right justified, and "F" formats must have the decimal point. The number of cards read per data block is listed at the bottom of each block.

2. Unformatted Data

While the USER'S MANUAL data sheet defines SADX data in formatted fields of ten, the data may actually be read in a simplified fashion by separating data by commas or one or more blanks. If more than one number is contained on an unformatted data card, a comma must appear somewhere on the card. If exponential numbers such as 2.5+10 are read on an unformatted card, there must be no imbedded blanks. Unformatted cards may be intermingled with formatted cards. Real numbers on an unformatted card must have a decimal point.

EXAMPLES

Unformatted data

5,7,3.2,1.3+6,-5,2

Equivalent formatted data

col	10	20	30	40	50	60	70	80
	5	7	3.2	1.3+6	-5	0	2	

Unformatted data

2

2,3

2 3

Equivalent formatted data

col	10	20	30	40	50	60	70	80
	2							
	2	3						

2 3

NOTE: The third line of data contains no commas and is therefore assumed to be already formatted.

Placement of more than eight unformatted data on a card will create two (or more) formatted cards as required. Fields of zeros will be created if more data are required than are filled on an unformatted card.

D. CONSTRAINTS

Constraints are calculated and stored in the G vector as listed in the following chart. The total number of constraints

$$NCON=\underbrace{NFREQ}_{freq}+\underbrace{2*NDSPLC}_{displ}+NLC*(\underbrace{2*NEB}_{stress} + \underbrace{4*NEF}_{stress} + \underbrace{NEB}_{buckl} + \underbrace{2*NEF}_{buckl})$$

Where NCON is the total number of constraints, NFREQ is the number of frequency constraints, NDSPLC is the number of displacement constraints, NLC is the number of load cases imposed, NEB is the number of bar or truss elements, and NEF is the number of frame elements. When any of the constraints are missing from the G vector, all constraints are moved up in the vector. For example, if there is no frequency constraint, then a displacement constraint would fill the first location of the G vector.

```
CONSTRAINTS ARE STORED IN THE G VECTOR IN
THE FOLLOWING ORDER:

NFREQ FREQUENCY CONSTRAINTS
2*NDSPLC JOINT DISPLACEMENT CONSTRAINTS
STRESS CONSTRAINTS ARE STORED ELEMENT BY ELEMENT
FOR A GIVEN ELEMENT CONSTRAINTS ARE STORED BY LOAD CASE
FOR A GIVEN TRUSS ELEMENT AND LOAD CASE,
CONSTRAINTS ARE STORED:
    TENSILE STRESS LOWER LIMIT
    TENSILE STRESS UPPER LIMIT
    EULER BUCKLING STRESS LIMIT (IF APPLICABLE)
FOR A GIVEN FRAME ELEMENT AND LOAD CASE,
CONSTRAINTS ARE STORED:
    NORMAL STRESS AT LOW NODE LOWER LIMIT
    NORMAL STRESS AT LOW NODE UPPER LIMIT
    NORMAL STRESS AT HIGH NODE LOWER LIMIT
```

NORMAL STRESS AT HIGH NODE UPPER LIMIT

EULER BUCKLING STRESS LIMIT (IF APPLICABLE)

LOCAL BUCKLING STRESS LIMIT (IF APPLICABLE)

E. EXAMPLE

The initial configuration of the braced cantilever beam is shown in Figure 5.1 Stress constraints are imposed as well as constraints on Euler and local buckling, displacement, and first fundamental frequency. A non-structural fixed mass is applied at the tip of the beam, and two load conditions (P1, and P2) are imposed. The structure's own weight will be considered as an imposed load as will be the fixed mass.

The linking of design variables is demonstrated by linking the mean diameters of the two frame members (D1, and D2 with D1=D2). Member size variables are: truss member areas (A1, and A2), frame member mean diameters (D1, and D2), and frame member thicknesses (T1, and T2). Member sizing DESIGN VARIABLES are: XA(1)=A1, XA(2)=A2, XA(3)=D1=D2, XA(4)=T1, XA(5)=T2.

Geometry variables are the attachment points (joints 4 and 5) of the two truss members on the y and z axes (Y4,Z5). Coordinate DESIGN VARIABLES are: XC(1)=Y4 and XC(2)=Z5. The structure's weight is then optimized with respect to member sizes and structure geometry for a total of seven design variables.

1. Properties/Conditions

Two material types are used: type 1, aluminum, is used for the truss members; and type 2, steel, is used for the frame members. The weight densities of the materials (ρ) are:

type 1 = 0.1 lb/in^3

type 2 = 0.3 lb/in^3

The Young's moduli of the materials (E) are:

type 1 E = 10.0E+6 psi

type 2 E = 29.0E+6 psi

The non-structural fixed mass attached at the tip of the structure weights 250 lb. The applied loads are:

P1 1000.0 lb in the +y direction

P2 1000.0 lb in the -z direction

The acceptable maximum normal stresses are:

type 1 $-25000 \text{ psi} \leq \sigma_{max} \leq 25000 \text{ psi}$

type 2 $-36000 \text{ psi} \leq \sigma_{max} \leq 36000 \text{ psi}$

Displacement limits, imposed upon joint number 3 (the tip) for each load case in the direction of loading, are:

load case 1	y-direction	+/- 3.0 in.
load case 2	z-direction	+/- 3.5 in.

Bounds, placed on the positions of joints 4 and 5 along the y and z axes, are:

joint 4	y-coordinate	0.0 inches to 200.0 inches
joint 5	z-coordinate	0.0 inches to 100.0 inches

The minimum natural frequency of the structure is constrained to be greater than 1Hz.

2. Input Control Parameters

The following input control parameters are given for ease of following the example:

NEB=2	NEF=2	NJ=5	NCJ=3
NMT=2	IDVCLC=2	NDJ=2	NEUBC=1
LBUCK=1	NFREQ=1	NFMASS=1	NEIG=1
NEIG1=2	NPRI=0	NLC=2	NDSPLC=2
NSTRES=2	NSTW=1	NFMW=1	

Table VI is a listing of commonly used nomenclature.

The following USER'S MANUAL is divided into blocks A through P. Appearing directly below each data field line are the parameters for the TRUSS-BRACED CANTILEVER BEAM example. It is important to note that the user may choose any consistent system of units.

TABLE VI

COMMON VARIABLE NOMENCLATURE

A	- MEMBER'S CROSS-SECTIONAL AREA
BL	- LOWER BOUND ON DISPLACEMENTS
BU	- UPPER BOUND ON DISPLACEMENTS
CHARDIM1,2	- CHARACTERISTIC DIMENSIONS FOR FRAME MEMBERS FOR LSECT.EQ.1: MEAN DIAMETER AND THICKNESS
DIR	- DIRECTION 1=X, 2=Y, 3=Z, 4=rot about x, 5=rot about y, 6=rot about z.
E	- YOUNGS MODULUS
EPSEIG	- CONVERGENCE TOLERANCE OF EIGENVALUE SOLUTIONS (DEFAULT=.0001)
FC1,...FCN	- LOWER BOUND ON FIRST,SECOND, ETC. SYSTEM NATURAL FREQUENCY
FX	- LOAD FORCES APPLIED IN THE X DIRECTION
FY	- LOAD FORCES APPLIED IN THE Y DIRECTION
FZ	- LOAD FORCES APPLIED IN THE Z DIRECTION
GRAV	- ACCELERATION DUE TO GRAVITY (DEFAULT= 386.4)
IDVCLC	- THE OPTIMIZATION OPERATION IDENTIFIER 1 FOR OPTIMUM MEMBER SIZE ONLY 2 FOR BOTH OPTIMUM MEMBER SIZE AND GEOMETRY 3 FOR OPTIMUM GEOMETRY ONLY
IX	- CONSTRAINT IDENTIFIER. IF NON-ZERO THE X-DOF IS CONSTRAINED
IY	- CONSTRAINT IDENTIFIER. IF NON-ZERO THE Y-DOF IS CONSTRAINED
IZ	- CONSTRAINT IDENTIFIER. IF NON-ZERO THE Z-DOF IS CONSTRAINED
IXX	- CONSTRAINT IDENTIFIER. IF NON-ZERO THE ROTATION ABOUT THE X-AXIS IS CONSTRAINED
IYY	- CONSTRAINT IDENTIFIER. IF NON-ZERO THE ROTATION ABOUT THE Y-AXIS IS CONSTRAINED
IZZ	- CONSTRAINT IDENTIFIER. IF NON-ZERO THE ROTATION ABOUT THE Z-AXIS IS CONSTRAINED
JN	- JOINT NUMBER (GLOBAL) KEULER- EULER BUCKLING COEFFICIENT FOR BAR ELEMENTS
LBUCK	- LOCAL BUCKLING CONSTRAINT IDENTIFIER IF LBUCK.NE.0, LOCAL BUCKLING CONSTRAINTS WILL BE APPLIED TO TUBULAR FRAME MEMBERS
LC	- LOAD CONDITION
LMASS	- LUMPED MASS OPTIONS IF LMASS.EQ.0 CONSISTENT MASS MATRIX USED IF LMASS.NE.0 LUMPED MASS MATRIX USED
LNO	- ELEMENT NUMBER
LSECT	- CROSS-SECTION TYPE IDENTIFIER LSECT.EQ.1 INDICATES A TUBULAR MEMBER
NCJ	- THE NUMBER OF CONSTRAINED JOINTS
NDJ	- THE NUMBER OF JOINTS WITH (OR LINKED TO) DESIGN VARIABLES
NDSG1	- TRUSS MEMBER AREA DESIGN VARIABLE NUMBER
NDSG2	- COORDINATE DESIGN VARIABLE NUMBER
NDSG3	- FRAME MEMBER CHARACTERISTIC DIMENSION 1 DESIGN VARIABLE NUMBER
NDSG4	- FRAME MEMBER CHARACTERISTIC DIMENSION 2 DESIGN VARIABLE NUMBER

```
NDSPLC    - THE NUMBER OF DISPLACEMENT CONSTRAINT SETS
NEB       - THE NUMBER OF TRUSS ELEMENTS
NEF       - THE NUMBER OF FRAME ELEMENTS
NEIG      - NUMBER OF PRECISE EIGENVALUES TO BE FOUND
NEIG1     - NUMBER OF EIGENVALUE/EIGENVECTOR TO BE
               EVALUATED DEFAULT =MIN(2*NEIG, NEIG+8)
NEUBC     - EULER BUCKLING CONSTRAINT IDENTIFIERS.
               IF NEUBC.NE.0 EULER BUCKLING CONSTRAINTS
               WILL BE IMPOSED ON BAR AND FRAME ELEMENTS
NFMASS    - NUMBER OF NON-STRUCTURAL FIXED MASSES
               ATTACHED TO THE STRUCTURE
NFMW      - FIXED MASS WEIGHT IDENTIFIER
               IF(NFMW.NE.0) FIXED MASSES WILL BE
               CONSIDERED AS LOADS
NFREQ     - NUMBER OF FREQUENCY CONSTRAINTS
NID       - NUMBER OF INDEPENDENT DEGREES OF FREEDOM
NJ        - THE NUMBER OF JOINTS
NLC       - NUMBER OF LOADING CONDTIONS
NLJ       - NUMBER OF LOADED JOINTS FOR THIS LOAD CONDITION
NMT       - NUMBER OF SEPARATE MATERIAL TYPES
NPRI      - INPUT PRINT CONTROL
               IF NPRI.NE.0 INPUT VALUES are NOT PRINTED
               IF NPRI.EQ.5 LOCI/LOCR/IA/RA ARRAYS PRINTED
NSTRES    - THE FORCE/STRESS PRINT IDENTIFIER
               IF NSTRES.EQ.0 MEMBER FORCES PRINTED
               IF NSTRES.EQ.1 MEMBER STRESSES PRINTED
               IF NSTRES.EQ.2 BOTH are PRINTED
NSTW      - STRUCTURE WEIGHT IDENTIFIER
               IF(NSTW.NE.0) THE STRUCTURE'S OWN WEIGHT
               WILL BE CONSIDERED AS LOADS
POISSN    - POISSON'S RATIO
RHO       - MATERIAL WEIGHT DENSITY
SIGMIN    - MINIMUM ALLOWABLE NORMAL STRESS
SIGMAX    - MAXIMUM ALLOWABLE NORMAL STRESS
TX        - TORSIONAL MOMENT APPLIED ABOUT THE X-AXIS
TY        - TORSIONAL MOMENT APPLIED ABOUT THE Y-AXIS
TZ        - TORSIONAL MOMENT APPLIED ABOUT THE Z-AXIS
XA        - INITIAL VALUE OF AREA DESIGN VARIABLE
XAL       - LOWER BOUNDS ON XA
XAU       - UPPER BOUNDS ON XA
XC        - INITIAL VALUE OF COORDINATE DESIGN VARIABLE
XCL       - LOWER BOUNDS ON XC
XCU       - UPPER BOUNDS ON XC
```

DATA BLOCK A

DESCRIPTION: Title Card

Format and Example

TITLE	FORMAT 20A4
TRUSS-BRACED CANTILEVER BEAM	

FIELD	CONTENTS
1	ANY 80 CHARACTER TITLE MAY BE GIVEN ON THIS LINE

DATA BLOCK B

DESCRIPTION: Control Parameters

Format and Example

NEB	NEF	NJ	NCJ	NMT	IDVCLC	NDJ	FORMAT 7I10
2	2	5	3	2	2	2	

NEUBC	LBUCK	NFREQ	NFMASS	NEIG	NEIG1	NPRI	format 7I10
1	1	1	1	1	2	0	

NLC	NDSPLC	NSTRES	NSTW	NFMW		FORMAT 5I10
2	2	2	1	1		

NOTE: DEFINITIONS OF PROGRAM INPUT CONTROL PARAMETERS ARE LISTED ON NEXT PAGE

FIELD	CONTENT
	FIRST CARD
1	NEB-number of bar elements
2	NEF-number of frame elements
3	NJ-number of joints
4	NCJ-number of constrained joints
5	NMT-number of seperate material types

6	IDVCLC-design variable control parameter
	If (IDVCLC.EQ.1) NDV=NDVAR1
	optimizes wrt member size only
	If (IDVCLC.EQ.2) NDV=NDVAR1+ NDVAR2
	optimizes wrt member size and geometry
	If (IDVCLC.EQ.3) NDV=NDVAR2
	optimizes wrt geometry only

7	NDJ-total linked and design variable joints (i.e. number of 'movable' joints)
	SECOND CARD
1	NEUBC-Euler buckling constraint identifier If (NEUBC.NE.0) EULER buckling constraints will be imposed on bar elements
2	LBUCK-local buckling constraint identifier If (LBUCK.NE.0) local buckling constraints will be imposed on tubular frame elements
3	NFREQ-number of frequency constraints
4	NFMASS-number of fixed masses attached to structure
5	NEIG-number of precise eigenvalues to be evaluated

6 NEIG1-number of eigenvalues to be evaluated

DEFAULT=min. of (2*NEIG , NEIG+8)

7 NPR1-print control identifier

NPR1.ne.0 input info not printed

NPR1.eq.5 RA/IA/LOCR/LOCI arrays

will be printed for debugging

THIRD CARD

1 NLC-number of load conditions

2 NDSPLC-number of displacement constraints

3 NSTRES-force/stress print identifier

If (NSTRES.EQ.0) stresses are printed

If (NSTRES.EQ.1) forces are printed

If (NSTRES.EQ.2) both are printed

4 NSTW-structure weight identifier

If (NSTW.NE.0) the structure's weight is considered as loads

5 NFMW-fixed mass weight identifier

If (NFMW.NE.0) the fixed masses are considered as loads

DATA BLOCK C

DESCRIPTION: Dynamic Analysis Information

Format and Example

LMASS	GRAV	EPSEIG		FORMAT
				I10,2F10.0
0	386.4	0.0		

FIELD	CONTENTS
1	LMASS-lumped mass option (if LMASS.NE.0) the lumped mass matrix is used.
2	GRAV-accleration due to gravity (default=386.4 inches/sec^2)
3	EPSEIG-convergence tolerance on eigenvalue solution. (default=.0001)

DATA BLOCK D

DESCRIPTION: Joint Coordinates

Format and Example

JN	X	Y	Z		FORMAT I10,3F10.0
1	0.0	0.0	0.0		
2	100.0	0.0	0.0		
3	200.0	0.0	0.0		
4	0.0	150.0	0.0		
5	0.0	0.0	50.0		

FIELD	CONTENTS
1	JN-joint coordinate number
2	X-x coordinate
3	Y-y coordinate
4	Z-z coordinate

NOTE: Number of cards read=NJ

DATA BLOCK E

Omit this block if NDJ=0 in BLOCK B

DESCRIPTION: Coordinate Design Variable Linking Data

Format and Example

JN	IX	IY	IZ	PCX	PCY	PCZ	FORMAT 4i10,3f10.0
4	0	1	0	1.0	1.0	1.0	
5	0	0	2	1.0	1.0	1.0	

FIELD	CONTENTS
1	IX-design variable associated with x coord.
2	IY-design variable associated with y coord.
3	IZ-design variable associated with z coord.
4	PCX-participation coefficient of x-coord.
5	PCY-participation coefficient of y-coord.
6	PCZ-participation coefficient of z-coord.

NOTE: Number of cards read=NDJ

DATA BLOCK F

DESCRIPTION: Material Properties

Format and Example

E	RHO	SIGMIN	SIGMAX	KEULER	POISSN	FORMAT 6F10.0
1.0E+7	0.1	-25000.	25000.	2.0	0.27	
2.9E+7	0.3	-36000.	36000.	2.0	0.27	

FIELD	CONTENTS
1	E-Young's Modulus
2	RHO-material density
3	SIGMIN-minimum allowable stress
4	SIGMAX-maximum allowable stress
5	KEULER-Euler buckling coefficient
6	POISSN-Poisson's ratio

NOTE: Number of cards read=NMT

DATA BLOCK G

Omit this block if NEB=0 in BLOCK B

DESCRIPTION: Bar Element Information

Format and Example

LNO	NODE1	NODE2	MATCOD	NDSG1	A	LSECT	FORMAT 5I10 f10,I10
3	2	4	1	1	3.0	1	
2	2	5	1	2	3.0	1	

FIELD	CONTENTS
1	LNO-element number
2	NODE1-global number associated with the element's 1st node
3	NODE2-global number associated with the element's 2nd node
4	MATCOD-material type of this element
5	NDSG1-design variable number associated with this element's area
6	A-member cross-sectional area
7	LSECT-cross-section type identifier LSECT.EQ.1 indicates a tubular member

NOTE: Number of cards read=NEB

DATA BLOCK H

Omit this block if NEF=0 in BLOCK B

DESCRIPTION: Frame Element Information Format and Example

LNO	NODE1	NODE2	MATCOD	NDSG3	NDSG4	LSECT	FORMAT 7I10
3	1	2	2	2	4	1	

CHARDIM1	CHARDIM2		FORMAT 2F10
5.0	1.0		

4	2	3	2	3	5	1

5.0	1.0

FIELD	CONTENTS
1	LNO-element number
2	NODE1-global number associated with the element's 1st node
3	NODE2-global number associated with the element's 2nd node
4	MATCOD-material type of this element
5	NDSG3-design variable number associated with the element's 1st characteristic dimension
6	NDSG4-design variable number associated with the element's 2nd characteristic dimension
7	LSECT-cross-section type identifier LSECT.EQ.1 indicates a tubular member

NOTE: Number of cards read=NEF

DATA BLOCK I

DESCRIPTION: Joint Constraint Information

Format and Example

JN	IX	IY	IZ	IXX	IYY	IZZ	FORMAT 7I10
1	1	1	1	1	1	1	
2	0	0	0	0	0	0	
3	0	0	0	0	0	0	
4	1	1	1	1	1	1	
5	1	1	1	1	1	1	

FIELD	CONTENTS
1	JN- joint number
2	IX- x-displacement constraint identifier.
3	IY- y-displacement constraint identifier.
4	IZ- z-displacement constraint identifier.
5	IXX- x-axis rotation constraint identifier.
6	IYY- y-axis rotation constraint identifier.
7	IZZ- z-axis rotation constraint identifier.

if .NE.0 - corresponding DOF constrained

NOTE: Number of cards read=NCJ

DATA BLOCK J

Omit this block if NLC=0 in BLOCK B.

DESCRIPTION: Joint Loading Information

Format and Example

NLJ		FORMAT I10

1	

JN	FX	FY	FZ	TX	TY	TZ	FORMAT I10,6F10
2	0.0	1000.	0.0	0.0	0.0	0.0	

1	

2	0.0	0.0	-1000.	0.0	0.0	0.0

FIELD	CONTENT
1	NLJ-number of loaded joints for this load condition
1	JN-joint number
2	FX
3	FY- Forces in the X,Y,Z directions
4	FZ
5	TX
6	TY- Moments about the X,Y,Z axes
7	TZ

NOTE: Number of cards read per set=NLJ
Number of sets of cards read=NLC

DATA BLOCK K

Omit this block if NFMASS=0 in BLOCK B

DESCRIPTION: Fixed Mass Information

Format and Example

JN	MASS		FORMAT I10,F10
3	250.0		

FIELD	CONTENTS
1	JN-joint number
2	MASS-point mass at joint (JN) in force units

NOTE: Number of cards read=NFMASS

DATA BLOCK L

Omit this block if IDVCLC=3

DESCRIPTION: Design Variable Information
(MEMBER SIZE VARIABLES)

Format and Example

XA (1)	XA (2)	. . . . XA (NDVAR1)	FORMAT 8F10.0

20.0	20.0	20.0	2.0	2.0

XAL (1)	XAL (2)	. . . . XAL (NDVAR1)	FORMAT 8F10.0

0.50	0.50	4.0	0.10	0.10

XAU (1)	XAU (2)	. . . . XAU (NDVAR1)	FORMAT 8F10.0

25.0	35.0	25.0	2.5	4.0

FIELD	CONTENTS
1	XA-initial value of area design variables
2	XAL-lower bounds on area design variables
3	XAU-upper bounds on area design variables

NOTE: read one value of XA, XAL, XAU for each independent member size variable defined in BLOCKS G and H

Number of cards read = as required

DATA BLOCK M

Omit this block if IDVCLC=1

DESCRIPTION: Design Variable Information
(COORDINATE VARIABLES)

Format and Example

XC(1)	XC(2)	. . . . XC(NDVAR2)	FORMAT 8F10.0

150.0	50.0

XCL(1)	XCL(2)	. . . .XCL(NDVAR2)	FORMAT 8F10.0

0.0	0.0

XCU(1)	XCU(2)	. . . .XCU(NDVAR2)	FORMAT 8F10.0

200.0	100.0

FIELD	CONTENTS
1	XC-initial value of coord. design variables
2	XCL-lower bounds on coord. design variables
3	XCU-upper bounds on coord. design variables

NOTE: read one value of XC,XCL,XCU for each independent coord. variable defined in BLOCK D

Number of cards read =as required.

DATA BLOCK N

Omit this block if NDSPLC=0 in BLOCK B

DESCRIPTION: Joint Displacement Constraint Information

Format and Example

JN	DIR	LC	BL	BU	FORMAT
					3I10,2F10.0

3	2	1	-3.0	3.0
3	3	2	-3.5	3.5

FIELD	CONTENTS
1	JN-joint number
2	DIR-direction 1=x,2=y,3=z displacement 4=x,5=y,6=z rotation
3	LC-load condition
4	BL-lower bound on displacement
5	BU-upper bound on displacement

NOTE: Number of cards read= NDSPLC

DATA BLOCK O

Omit this block if NFREQ=0 in BLOCK B

DESCRIPTION: Frequency Constraint Information

Format and Example

FC1	FC2	FC3	.......FCN	FORMAT 8F10.0
1.0				

FIELD	CONTENTS
1	FC1- lower bound on first natural frequency constraint in Hz. (cycles per second)
N	FCN- lower bound on NFREQ-th natural frequency constraint in Hz. (cycles per second)

NOTE: Number of cards read = as required

DATA BLOCK P

DESCRIPTION: End card

Format and Example

END		FORMAT 3A1

END

NOTE: This card MUST appear at the end of the SADX data.

VI. NUMERICAL EXAMPLES

A. INTRODUCTION

Design of three-dimensional truss and frame structures are presented herein and the corresponding numerical results are summarized to demonstrate the use of the SADX code.

The examples begin with the truss-braced cantiliver beam.

B. EXAMPLE 1: TRUSS-BRACED CANTILIVER BEAM

The simple truss-braced cantiliver beam, as shown in Figure 6.1, has been previously used for the SADX USER's MANUAL example. It consists of two steel tubular frame members with a common outer diameter and different wall thicknesses arranged as a cantilever beam along the X-axis. There is a fixed 250 pound mass at the tip of the beam. Two aluminum truss members are attached from the beam mid-point to points on the Y and Z axes. This structure is designed for optimum member size and geometry under a set of two load conditions and subject to constraints on maximum stress, maximum joint displacement, Euler and local buckling, and minimum structure natural frequencies. The weight of the non-structural fixed mass and the structure's own weight are imposed as loads. There are five member size and two coordinate design variables, and a total of 41 constraints.

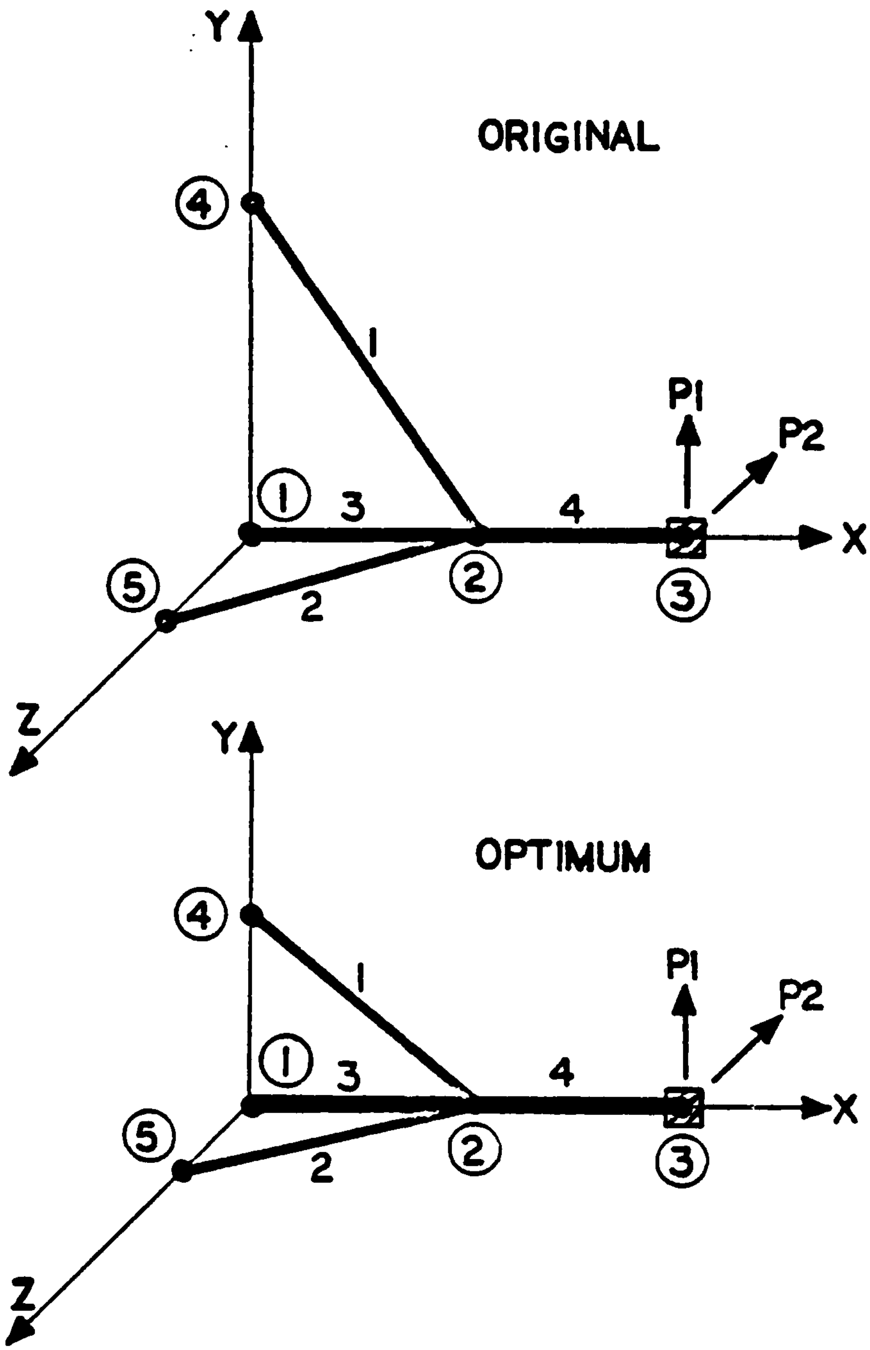

Figure 6.1 TRUSS-BRACED CANTILEVER BEAM

The number of analyses required for this design is 116 using 2.75 seconds of CPU time and terminating on the 12th iteration. Of the analyses conducted, 84 were required for the calculation of gradients. The weight of the structure, including non-structural fixed masses, is reduced from 9542 pounds to 838 pounds. Results are given in Table VII.

C. EXAMPLE 2: TWO-TIER 3-D PORTAL FRAME WITH TRUSS X-BRACES

The two-tier three-dimensional portal frame with truss member diagonal braces, as shown in Figure 6.2, is a symmetric moderately sized case that can be analyzed easily by a variety of other codes. There are 20 truss elements, 16 frame elements, and four non-structural fixed masses. The material used is steel. This structure is designed for optimum member size and geometry under a set of three load conditions and subject to constraints on maximum stress, maximum joint displacement, Euler and local buckling, and minimum structure natural frequencies. The weight of the non-structural fixed masses and the structure's own weight are imposed as loads. There are 10 member size and five coordinate design variables and a total of 493 constraints. The number of analyses required for this design is 385 using 120 seconds of CPU time and terminating on the 21st iteration. Of the analyses conducted, 305 were required for the calculation of gradients. The weight of the structure, including non-structural fixed masses, is reduced from 9302 pounds to 1462 pounds. Results are given in Table VIII.

TABLE VII

EXAMPLE 1: FINAL OPTIMIZATION INFORMATION

```
FINAL OPTIMIZATION INFORMATION

 OBJ =    0.587507E+03

 THERE ARE    1 ACTIVE CONSTRAINTS
 CONSTRAINT NUMBERS ARE
    36

 THERE ARE    0 VIOLATED CONSTRAINTS

 THERE ARE    0 ACTIVE SIDE CONSTRAINTS

 TERMINATION CRITERION
 ABS(OBJ(I)-OBJ(I-1)) LESS THAN DABFUN FOR 3 ITERATIONS

 NUMBER OF ITERATIONS =   12

 OBJECTIVE FUNCTION WAS EVALUATED            114   TIMES

 CONSTRAINT FUNCTIONS WERE EVALUATED         114   TIMES

 THIS RUN REQUIRED  116  STRUCTURAL ANALYSES

 NUMBER OF SECONDS REQUIRED FOR EXECUTION = 2.79

 WEIGHT OF STRUCTURE GIVEN AREAS & LENGTHS
 WEIGHT=      0.58751E+03

 TOTAL WEIGHT INCLUDING FIXED MASSES
 TOTAL WEIGHT=      0.83751E+03

 JOINT COORDINATES
JOINT           X                  Y                  Z
   1       0.0               0.0                0.0
   2       0.10000E+03       0.0                0.0
   3       0.20000E+03       0.0                0.0
   4       0.0               0.84259E+02        0.0
   5       0.0               0.0                0.45432E+02

 ELEMENT INFORMATION FOR BAR ELEMENTS

 ELEMENT-JOINT RELATIONSHIPS

ELEMENT  NODE 1  NODE 2      AREA          LENGTH
   1        2       4     0.3481E+01     0.1308E+03
   2        2       5     0.8499E+01     0.1098E+03

 ELEMENT INFORMATION FOR FRAME ELEMENTS

 ELEMENT-JOINT RELATIONSHIPS

 LNC NODE1 NODE2    AREA        LENGTH     CHAR.DIM.1   CHAR.DIM.2
  3    1     2   0.3329E+01  0.1000E+03  0.4839E+01  0.2190E+00
  4    2     3   0.2368E+01  0.1000E+03  0.4839E+01  0.1558E+00

EIGENVALUES AND EIGENVECTORS

MODE NUMBER      1
FREQUENCY   =  0.41988E+02 CPS
               0.26319E+03 RPS
EIGENVALUE  =  0.69270E+05
EIGENVECTOR    DEGREE OF FREEDOM
JOINT          1               2               3
   1      0.0             0.0             0.0
   2      0.0             0.0             0.0
   3     -0.23435E-01    -0.32985E-01    -0.74507E-01
   4     -0.50777E-01    -0.10745E-01     0.15830E-03
   5     -0.23435E-01    -0.17155E-01     0.10000E+01
```

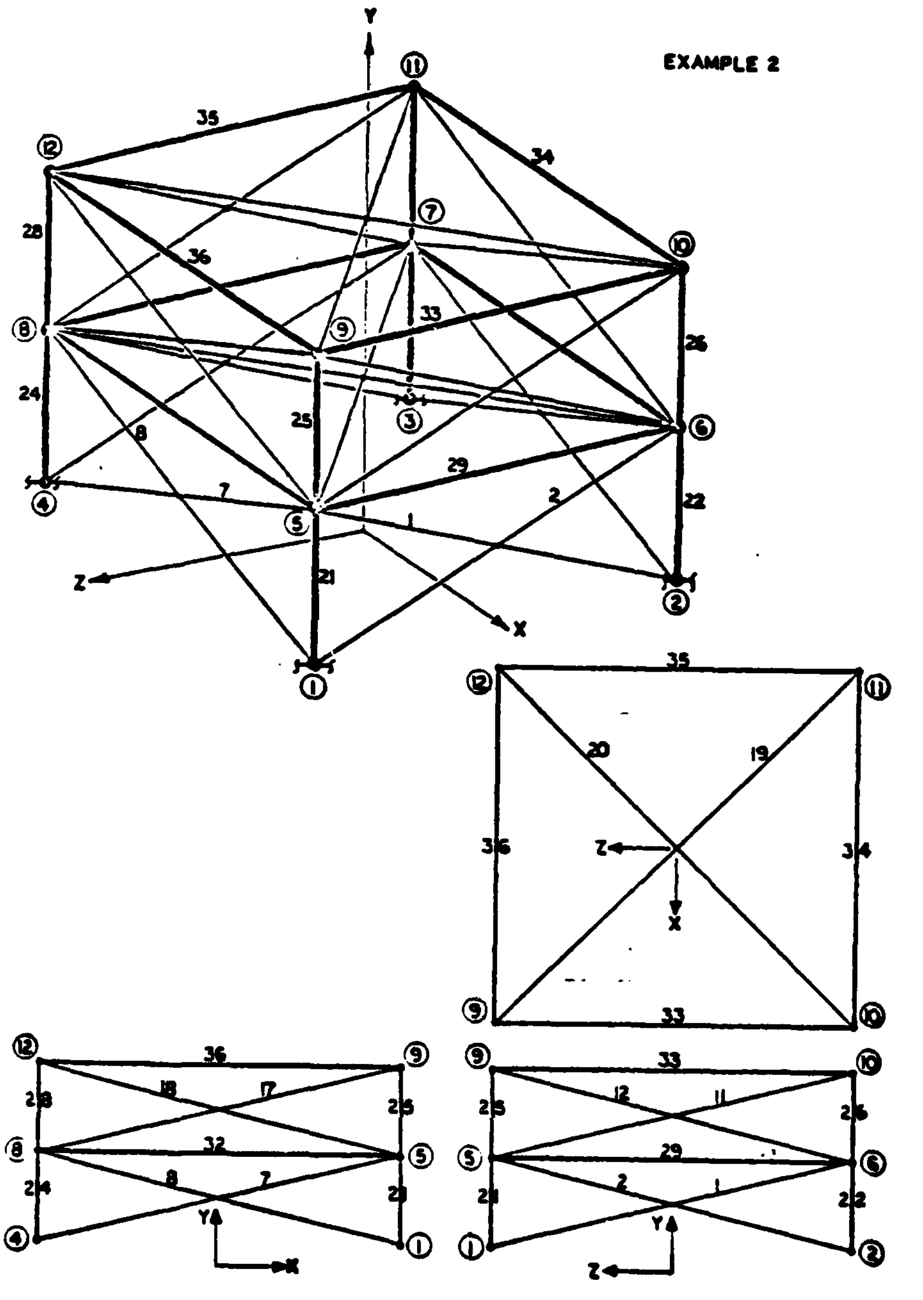

Figure 6.2 TWO-TIER 3-D PORTAL FRAME WITH TRUSS X-BRACES

TABLE VIII

EXAMPLE 2: FINAL OPTIMIZATION INFORMATION

```
FINAL OPTIMIZATION INFORMATION

OBJ =    0.144183E+04

THERE ARE    3 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
   46   91  196

THERE ARE    0 VIOLATED CONSTRAINTS

THERE ARE    1 ACTIVE SIDE CONSTRAINTS
DECISION VARIABLES AT LOWER OR UPPER BOUNDS
(MINUS INDICATES LOWER BOUND)
  -14

TERMINATION CRITERION
ABS(OBJ(I)-OBJ(I-1)) LESS THAN DABFUN FOR 3 ITERATIONS

NUMBER OF ITERATIONS =    21

OBJECTIVE FUNCTION WAS EVALUATED          383  TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED       383  TIMES

THIS RUN REQUIRED  385  STRUCTURAL ANALYSES

NUMBER OF SECONDS REQUIRED FOR EXECUTION = 120.7

WEIGHT OF STRUCTURE GIVEN AREAS & LENGTHS
WEIGHT=      0.14418E+04

TOTAL WEIGHT INCLUDING FIXED MASSES
TOTAL WEIGHT=      0.16418E+04

JOINT COORDINATES
```

JOINT	X	Y	Z
1	0.63385E+02	0.0	0.90002E+02
2	0.63385E+02	0.0	-0.90002E+02
3	-0.63385E+02	0.0	-0.90002E+02
4	-0.63385E+02	0.0	0.90002E+02
5	0.80239E+02	0.20000E+02	0.69074E+02
6	0.80239E+02	0.20000E+02	-0.69074E+02
7	-0.80239E+02	0.20000E+02	-0.69074E+02
8	-0.80239E+02	0.20000E+02	0.69074E+02
9	0.10000E+03	0.10000E+03	0.10000E+03
10	0.10000E+03	0.10000E+03	-0.10000E+03
11	-0.10000E+03	0.10000E+03	-0.10000E+03
12	-0.10000E+03	0.10000E+03	0.10000E+03

```
ELEMENT INFORMATION FOR BAR ELEMENTS
ELEMENT-JOINT RELATIONSHIPS
```

ELEMENT	NODE 1	NODE 2	AREA	LENGTH
1	1	6	0.4255E+00	0.1612E+03
2	2	5	0.4255E+00	0.1612E+03
3	2	7	0.4255E+00	0.1465E+03
4	3	6	0.4255E+00	0.1465E+03
5	3	8	0.4255E+00	0.1612E+03
6	4	7	0.4255E+00	0.1612E+03
7	4	5	0.4255E+00	0.1465E+03
8	1	8	0.4255E+00	0.1465E+03
9	5	7	0.4255E+00	0.2118E+03
10	6	8	0.4255E+00	0.2118E+03
11	5	10	0.1544E+01	0.1881E+03
12	6	9	0.1544E+01	0.1881E+03
13	6	11	0.1544E+01	0.1996E+03

D. EXAMPLE 3: DD-963 FOREMAST

Example three is a redesign of the forward mast on the DD-963 of SPRUANCE class destroyer. The DD-963 foremast has been chosen as the third test case for the following reasons: 1) the structure is typical of the masts found on many combatants in the United States and other navies, 2) high topside weight reduction is desirable from a stability viewpoint for any ship, 3) the structural members are predominantly tubular, 4) the problem is sufficiently complex to make conventional design methods cumbersome, 5) the member size and loading information is available.

The structure as shown in Figures 6.3 through 6.6 is constructed of 172 aluminum frame members. The material used in the structure is 5086 H32 aluminum, an alloy with moderate strength, good weldability, and good corrosion resistance.

This structure is designed for optimum member size under a single load condition and subject to constraints on maximum member stress, maximum joint displacement, Euler and local buckling.

Some structural simplifications are made. The weights of mast-mounted radars, antennas, and platforms are modeled by a series of fixed masses which are imposed as loads along with the structure's own weight. The forces due to halyards and wire antennas are applied as loads. Inertial forces due to ships motion are calculated for the initial design point

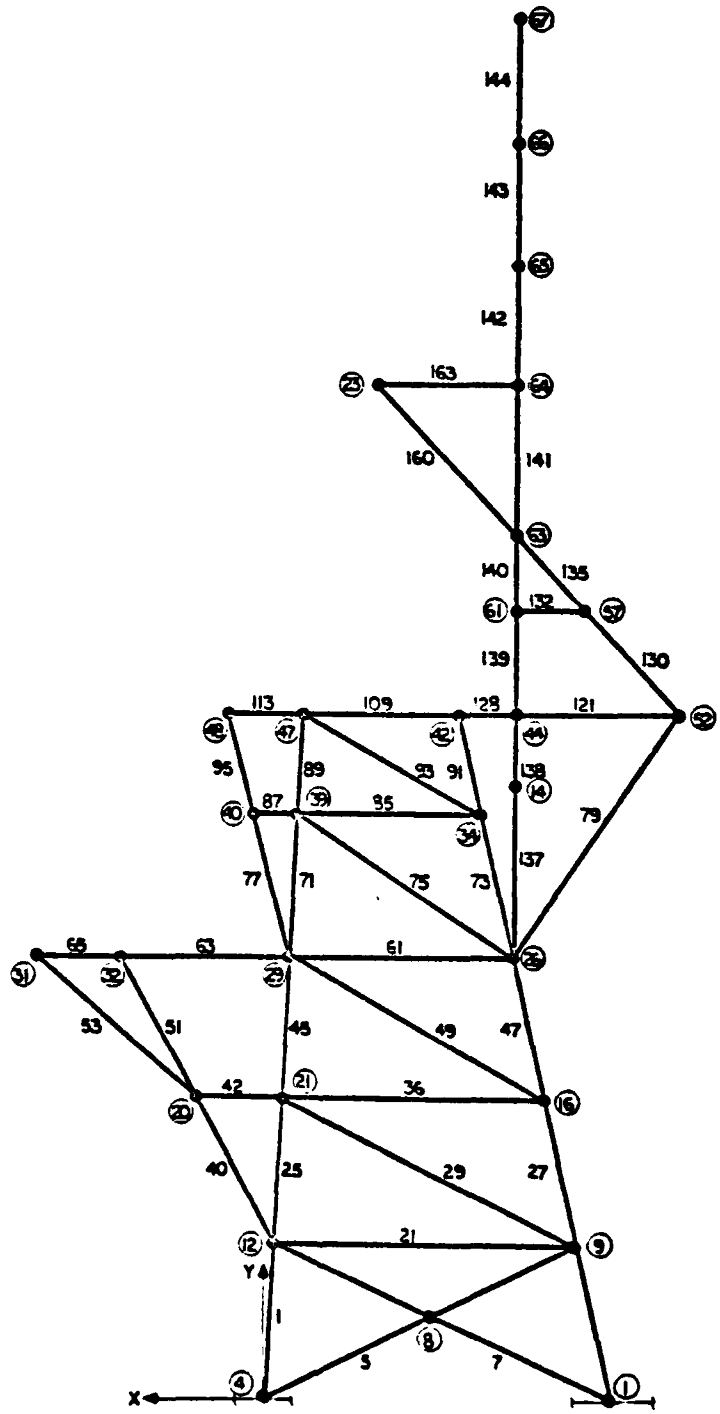

Figure 6.3 DD-963 FOREMAST PORT SIDE

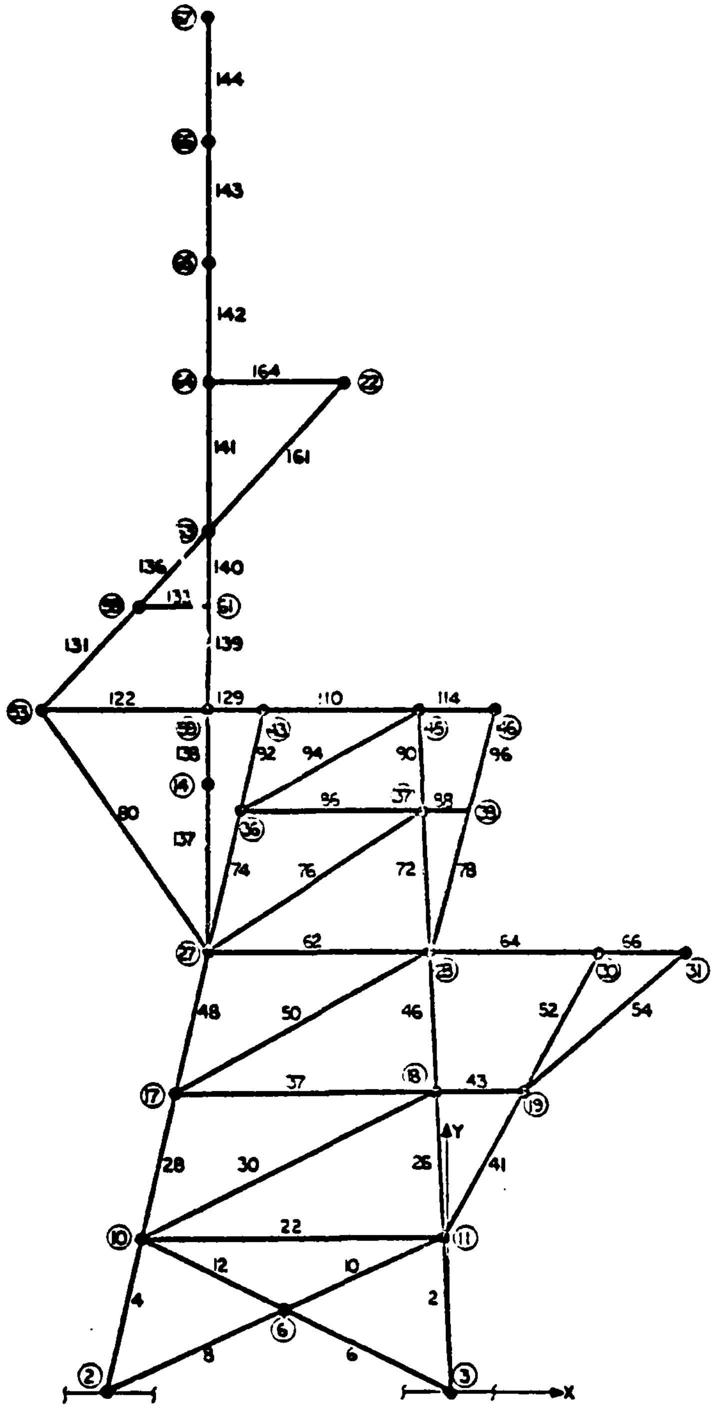

Figure 6.4 DD-963 FOREMAST STARBOARD SIDE

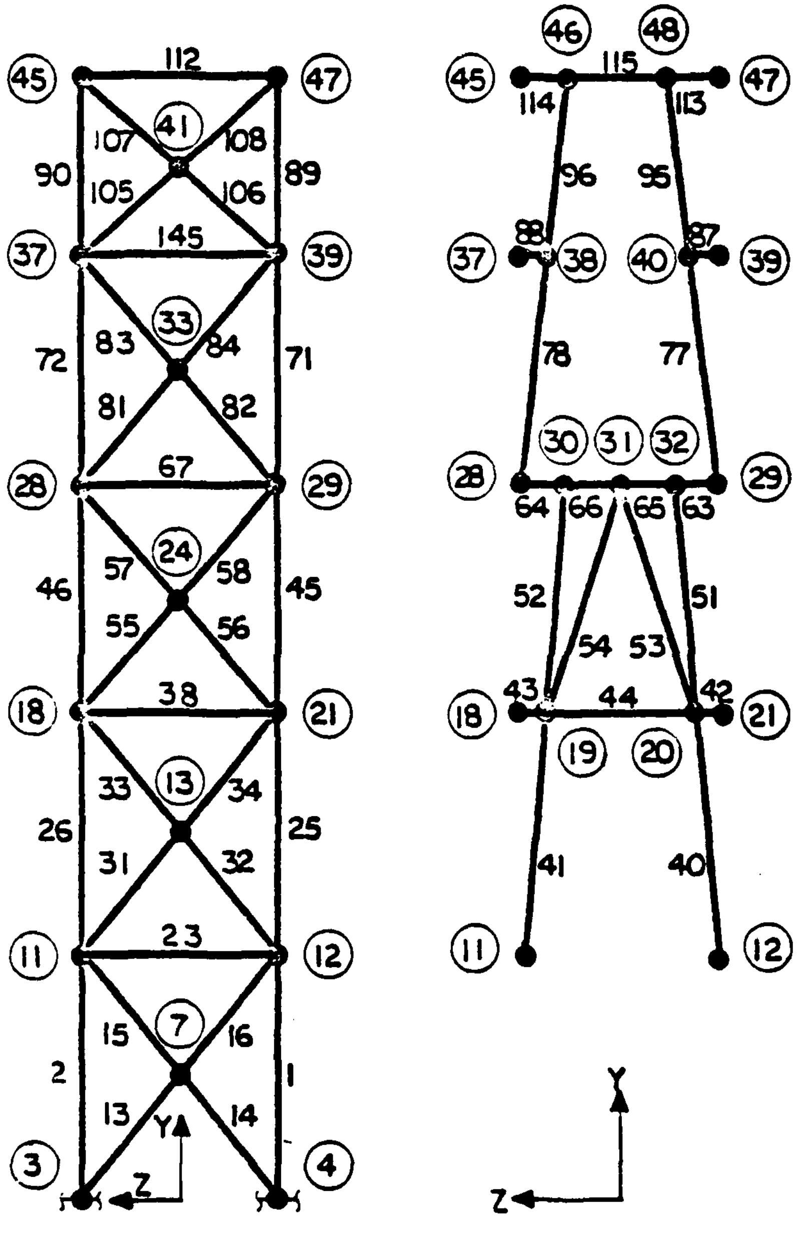

Figure 6.5 DD-963 FOREMAST FORWARD SIDE

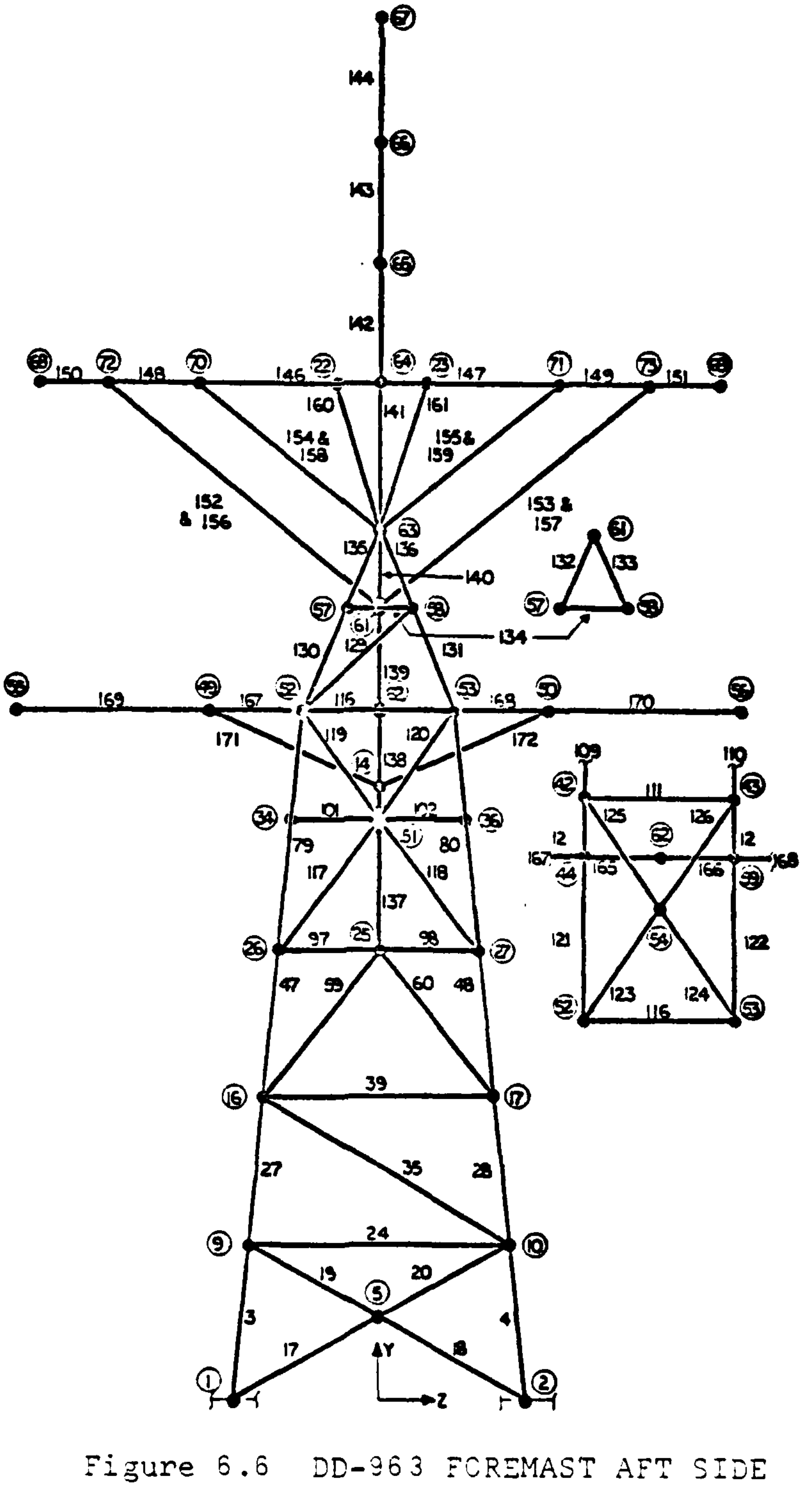

Figure 6.6 DD-963 FOREMAST AFT SIDE

and consist of the product of a member's half-weight and a coordinate-dependent load-factor applied at each end of the element [Ref. 6]. The load-factor multiplier is dependent on the distances from a point at the intersection of the design waterline and the ship centerline amidships (frame 264 1/2). Ship's motion loads are applied for a roll to port. In that the purpose of this example is only to attempt to solve a large and messy problem rather than to produce an actual design no attempt is made to include wind, shock, and blast loads. There are 34 member size design variables and a total of 1054 constraints. The number of analyses required for this design is 555 using 4482 seconds of CPU time and terminating on the 17th iteration. Of the analyses conducted, 544 were required for the calculation of gradients. The weight of the structure, including non-structural fixed masses, is increased from 48,199 pounds to 56,746 pounds. The structure as modeled was initially infeasible due, most likely to the structural simplifications made in the topmast area. Results are given in Table IX.

TABLE IX

EXAMPLE 3: FINAL OPTIMIZATION INFORMATION

```
FINAL OPTIMIZATION INFORMATION

OBJ =     0.39864E+05

THERE ARE    2 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
  860  866

THERE ARE    0 VIOLATED CONSTRAINTS

THERE ARE    0 ACTIVE SIDE CONSTRAINTS

TERMINATION CRITERION
ABS(OBJ(I)-OBJ(I-1) LESS THAN DABFUN FOR 3 ITERATIONS

NUMBER OF ITERATIONS =    17

OBJECTIVE FUNCTION WAS EVALUATED          553   TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED       553   TIMES

THIS RUN REQUIRED  555  STRUCTURAL ANALYSES

WEIGHT OF STRUCTURE GIVEN AREAS & LENGTHS
WEIGHT=     0.39860E+05

TOTAL WEIGHT INCLUDING FIXED MASSES
TOTAL WEIGHT=     0.56746E+05

NUMBER OF SECONDS REQUIRED FOR EXECUTION = 4482.46

NO. OF FRAME ELEMENTS =  172
ELEMENT-JOINT RELATIONSHIPS
```

LNO	NODE1	NODE2	AREA	LENGTH	CHAR.DIM.1	CHAR.DIM.2
1	4	12	0.5979E+02	0.1081E+03	0.1900E+02	0.1002E+01
2	3	11	0.5979E+02	0.1081E+03	0.1900E+02	0.1002E+01
3	1	9	0.5979E+02	0.1112E+03	0.1900E+02	0.1002E+01
4	2	10	0.5979E+02	0.1112E+03	0.1900E+02	0.1002E+01
5	4	8	0.6247E+01	0.1342E+03	0.6563E+01	0.3030E+00
6	3	6	0.6247E+01	0.1342E+03	0.6563E+01	0.3030E+00
7	1	8	0.6247E+01	0.1369E+03	0.6563E+01	0.3030E+00
8	2	6	0.6247E+01	0.1369E+03	0.6563E+01	0.3030E+00
9	8	12	0.6247E+01	0.1295E+03	0.6563E+01	0.3030E+00
10	6	11	0.6247E+01	0.1295E+03	0.6563E+01	0.3030E+00
11	8	9	0.6247E+01	0.1132E+03	0.6563E+01	0.3030E+00
12	6	10	0.6247E+01	0.1132E+03	0.6563E+01	0.3030E+00
13	3	7	0.6247E+01	0.6846E+02	0.6563E+01	0.3030E+00
14	4	7	0.6247E+01	0.6846E+02	0.6563E+01	0.3030E+00
15	7	11	0.6247E+01	0.6846E+02	0.6563E+01	0.3030E+00
16	7	12	0.6247E+01	0.6846E+02	0.6563E+01	0.3030E+00
17	1	5	0.6247E+01	0.1196E+03	0.6563E+01	0.3030E+00
18	2	5	0.6247E+01	0.1196E+03	0.6563E+01	0.3030E+00
19	5	9	0.6247E+01	0.1097E+03	0.6563E+01	0.3030E+00
20	5	10	0.6247E+01	0.1097E+03	0.6563E+01	0.3030E+00
21	9	12	0.6247E+01	0.2172E+03	0.6563E+01	0.3030E+00
22	10	11	0.6247E+01	0.2172E+03	0.6563E+01	0.3030E+00
23	11	12	0.6247E+01	0.8400E+02	0.6563E+01	0.3030E+00
24	9	10	0.6247E+01	0.1894E+03	0.6563E+01	0.3030E+00
25	12	21	0.5979E+02	0.1081E+03	0.1900E+02	0.1002E+01
26	11	18	0.5979E+02	0.1081E+03	0.1900E+02	0.1002E+01
27	9	16	0.5979E+02	0.1111E+03	0.1900E+02	0.1002E+01
28	10	17	0.5979E+02	0.1111E+03	0.1900E+02	0.1002E+01
29	9	21	0.7358E+01	0.2380E+03	0.7767E+01	0.3016E+00
30	10	18	0.7358E+01	0.2380E+03	0.7767E+01	0.3016E+00
31	11	13	0.7358E+01	0.6846E+02	0.7767E+01	0.3016E+00
32	12	13	0.7358E+01	0.6846E+02	0.7767E+01	0.3016E+00

33	13	18	0.7358E+01	0.6846E+02	0.7767E+01	0.3016E+00
34	13	21	0.7358E+01	0.6846E+02	0.7767E+01	0.3016E+00
35	10	16	0.7358E+01	0.2094E+03	0.7767E+01	0.3016E+00
36	16	21	0.5424E+01	0.1866E+03	0.5024E+01	0.3437E+00
37	17	18	0.5424E+01	0.1866E+03	0.5024E+01	0.3437E+00
38	18	21	0.5424E+01	0.8400E+02	0.5024E+01	0.3437E+00
39	16	17	0.5424E+01	0.1663E+03	0.5024E+01	0.3437E+00
40	12	20	0.5424E+01	0.1232E+03	0.5024E+01	0.3437E+00
41	11	19	0.5424E+01	0.1232E+03	0.5024E+01	0.3437E+00
42	20	21	0.5424E+01	0.6456E+02	0.5024E+01	0.3437E+00
43	18	19	0.5424E+01	0.6456E+02	0.5024E+01	0.3437E+00
44	19	20	0.5424E+01	0.8400E+02	0.5024E+01	0.3437E+00
45	21	29	0.5979E+02	0.1081E+03	0.1900E+02	0.1002E+01
46	18	28	0.5979E+02	0.1081E+03	0.1900E+02	0.1002E+01
47	16	26	0.5979E+02	0.1112E+03	0.1900E+02	0.1002E+01
48	17	27	0.5979E+02	0.1112E+03	0.1900E+02	0.1002E+01
49	16	29	0.1098E+02	0.2112E+03	0.9952E+01	0.3511E+00
50	17	28	0.1098E+02	0.2112E+03	0.9952E+01	0.3511E+00
51	20	32	0.5424E+01	0.1209E+03	0.5024E+01	0.3437E+00
52	19	30	0.5424E+01	0.1209E+03	0.5024E+01	0.3437E+00
53	20	31	0.1098E+02	0.1626E+03	0.9952E+01	0.3511E+00
54	19	31	0.1098E+02	0.1626E+03	0.9952E+01	0.3511E+00
55	18	24	0.1098E+02	0.6846E+02	0.9952E+01	0.3511E+00
56	21	24	0.1098E+02	0.6846E+02	0.9952E+01	0.3511E+00
57	24	28	0.1098E+02	0.6846E+02	0.9952E+01	0.3511E+00
58	24	29	0.1098E+02	0.6846E+02	0.9952E+01	0.3511E+00
59	16	25	0.1098E+02	0.1384E+03	0.9952E+01	0.3511E+00
60	17	25	0.1098E+02	0.1384E+03	0.9952E+01	0.3511E+00
61	26	29	0.1648E+02	0.1558E+03	0.1082E+02	0.4848E+00
62	27	28	0.1648E+02	0.1558E+03	0.1082E+02	0.4848E+00
63	29	32	0.1648E+02	0.1240E+03	0.1082E+02	0.4848E+00
64	28	30	0.1648E+02	0.1240E+03	0.1082E+02	0.4848E+00
65	31	32	0.1648E+02	0.7684E+02	0.1082E+02	0.4848E+00
66	30	31	0.1648E+02	0.7684E+02	0.1082E+02	0.4848E+00
67	28	29	0.1648E+02	0.8400E+02	0.1082E+02	0.4848E+00
68	15	60	0.3142E-06	0.1000E+00	0.0	0.0
69	15	60	0.3142E-06	0.1000E+00	0.0	0.0
70	30	32	0.1648E+02	0.9600E+02	0.1082E+02	0.4848E+00
71	29	39	0.5979E+02	0.9611E+02	0.1900E+02	0.1002E+01
72	28	37	0.5979E+02	0.9611E+02	0.1900E+02	0.1002E+01
73	26	34	0.5979E+02	0.9879E+02	0.1900E+02	0.1002E+01
74	27	36	0.5979E+02	0.9879E+02	0.1900E+02	0.1002E+01
75	26	39	0.1667E+02	0.1792E+03	0.1056E+02	0.5026E+00
76	27	37	0.1667E+02	0.1792E+03	0.1056E+02	0.5026E+00
77	29	40	0.1667E+02	0.1000E+03	0.1056E+02	0.5026E+00
78	28	38	0.1667E+02	0.1000E+03	0.1056E+02	0.5026E+00
79	26	52	0.1667E+02	0.2066E+03	0.1056E+02	0.5026E+00
80	27	53	0.1667E+02	0.2066E+03	0.1056E+02	0.5026E+00
81	28	33	0.1667E+02	0.6382E+02	0.1056E+02	0.5026E+00
82	29	33	0.1667E+02	0.6382E+02	0.1056E+02	0.5026E+00
83	33	37	0.1667E+02	0.6382E+02	0.1056E+02	0.5026E+00
84	33	39	0.1667E+02	0.6382E+02	0.1056E+02	0.5026E+00
85	34	39	0.1667E+02	0.1289E+03	0.1056E+02	0.5026E+00
86	36	37	0.1667E+02	0.1289E+03	0.1056E+02	0.5026E+00
87	39	40	0.1667E+02	0.3254E+02	0.1056E+02	0.5026E+00
88	37	38	0.1667E+02	0.3254E+02	0.1056E+02	0.5026E+00
89	39	47	0.5979E+02	0.7209E+02	0.1900E+02	0.1002E+01
90	37	45	0.5979E+02	0.7209E+02	0.1900E+02	0.1002E+01
91	34	42	0.5979E+02	0.7411E+02	0.1900E+02	0.1002E+01
92	36	43	0.5979E+02	0.7411E+02	0.1900E+02	0.1002E+01
93	34	47	0.1697E+02	0.1446E+03	0.1035E+02	0.5219E+00
94	36	45	0.1697E+02	0.1446E+03	0.1035E+02	0.5219E+00
95	40	48	0.1667E+02	0.7428E+02	0.1056E+02	0.5026E+00
96	38	46	0.1667E+02	0.7428E+02	0.1056E+02	0.5026E+00
97	25	26	0.1667E+02	0.7176E+02	0.1056E+02	0.5026E+00
98	25	27	0.1667E+02	0.7176E+02	0.1056E+02	0.5026E+00
99	26	35	0.1667E+02	0.1217E+03	0.1056E+02	0.5026E+00
100	27	35	0.1667E+02	0.1217E+03	0.1056E+02	0.5026E+00
101	34	35	0.1667E+02	0.6168E+02	0.1056E+02	0.5026E+00
102	35	36	0.1667E+02	0.6168E+02	0.1056E+02	0.5026E+00
103	35	42	0.1667E+02	0.9138E+02	0.1056E+02	0.5026E+00
104	35	43	0.1667E+02	0.9138E+02	0.1056E+02	0.5026E+00

VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

An existing finite element code was expanded to encompass the more general case of frame members; i.e., six degrees of freedom per joint. Combined truss and frame structures were designed for minimum weight with multiple load conditions considered.

The displacement method was used for static analysis and the subspace iteration method was used for eigenvalues.

Several examples were considered. In every case the code worked as an analysis tool, and significant weight reductions were obtained with the coupled optimizer *CONMIN*.

The SADX design code has been shown to be a useful tool for ship mast optimum design.

B. RECOMMENDATIONS

The following recommendations may be of value for future work.

1. The routines necessary to calculate gradients analytically should be added to the code.

2. The code should be extended to include plate and shear elements and a library of member cross-sections.

3. An out of core equation solver should be added.

4. The ability to specify multipliers for applying inertial loads along the three coordinate axes should be added in a fashion similar to that used for applying structure's own weight as loads. Such an addition would simplify dynamic load analysis and design.

5. The method of gradient calculation should be dependent on specific gradients required [Ref. 7] and [Ref. 8].

6. Gradients of frequency constraints would benefit from a more efficient algorithm [Ref. 9].

7. The need for a large scale public structural optimization code still exists.

8. The code should be modified to allow optimum member size design followed by simultaneous optimum member size and optimum geometry design.

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APPENDIX A

DATA FILES

A. INTRODUCTION

This appendix contains the data files used to create the test cases in Chapter VI. Additionally the data file for the USER'S guide in complete form is presented.

TABLE X

DATA FILE TRUSS-BRACED CANTILEVER BEAM

```
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK A TITLE                                   1 CARD     FORMAT  80H
TRUSS-BRACED CANTILEVER BEAM: EXAMPLE 1
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK B CONTROL PARAMETERS                      3 CARDS    FORMAT  8I10
$   NEB       NEF       NJ        NCJ       NMT       IDVCLC    NDJ
$        |         |         |         |         |         |         |
         2         2         5         3         2         2         2
$ NEUBC     LBUCK     NFREQ     NFMASS    NEIG      NEIG1     NPRI
$        |         |         |         |         |         |         |
         1         1         1         1         1         2         0
$  NLC      NOSPLC    NSTRES    NSTW      NFMW
$        |         |         |         |         |
         2         2         2         1         1
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK C DYNAMIC ANALYSIS INFORMATION  1 CARD    FORMAT  I10,2F10.0
$ LMASS     GRAV      EPSEIG
$        |         |         |
         0     386.4        0.
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK C JOINT COORDINATES
$   NJ CARDS                                     FORMAT I10,3F10
$   JN     X-COORD   Y-COORD   Z-COORD
$        |         |         |         |
         1        0.        0.        0.
         2      100.        0.        0.
         3      200.        0.        0.
         4        0.      150.        0.
         5        0.        0.       50.
$BLOCK E DESIGN VARIABLE LINKING DATA
$   NDJ CARDS                                    FORMAT 4I10,3F10.0
$   JN        IX        IY        IZ        PCX       PCY       PCZ
$        |         |         |         |         |         |         |
         4         0         1         0       1.0       1.0       1.0
         5         0         0         2       1.0       1.0       1.0
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK F MATERIAL PROPERTIES             NMT CARDS    FORMAT  6F10.0
$   E         RFC       SIGMIN    SIGMAX    KEULER    POISSN
$        |         |         |         |         |         |
    1.0E+7       0.1   -25000.    25000.        2.       .27
    2.9E+7       0.3   -36000.    36000.        2.       .27
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK G BAR ELEMENT INFORMATION         NEB CARDS    FORMAT  5I10,F10,I10
$   LNO       NODE2     NODE3     MATCOD    NSDG1     AREA      LSECT
$        |         |         |         |         |         |         |
         1         2         4         1         1       3.0         1
         2         2         5         1         2       3.0         1
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK H FRAME ELEMENT INFORMATION         2*NEF CARDS FORMAT 7I10/2F10
$   LNO       NODE2     NODE3     MATCOD    NSDG1     NSDG2     LSECT
$        |         |         |         |         |         |         |
         3         1         2         2         3         4         1
$CHARDIM1 CHARDIM2
$        |         |
       5.0       1.0
         4         2         3         2         3         5         1
       5.0       1.0
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK I JOINT CONSTRAINT DATA         NCJ CARDS    FORMAT  7I10
$   JN        IX        IY        IZ        IXX       IYY       IZZ
$        |         |         |         |         |         |         |
         1         1         1         1         1         1         1
         2         0         0         0         0         0         0
         3         0         0         0         0         0         0
         4         1         1         1         1         1         1
         5         1         1         1         1         1         1
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK J JOINT LOADING DATA                  1 CARD    FORMAT I10
$      (OMIT IF NLC=0 IN BLOCK B)
$  NLJ
$        |
         1
```

TABLE XI

DATA FILE TRUSS-BRACED CANTILEVER BEAM continued

```
$                                         NLJ CARDS   FORMATI10,6F10
$   JN         FX         FY        FZ         TX         TY         TZ
$         |         |         |         |         |         |         |
          3        0.    1000.0        0.        0.        0.        0.
          1
          3        0.       0.0   -1000.0        0.        0.        0.
$********1*********2*********3*********4*********5*********6*********7*********
$BLOCK K FIXED MASS DATA          NFMASS CARDS   FORMAT I10,F10.0
$     (OMIT IF NFMASS=0 IN BLOCK B)
$   JN      MASS
$         |         |
          3     250.0
$********1*********2*********3*********4*********5*********6*********7*********
$BLOCK L DESIGN VARIABLE INFORMATION   CARDS AS REQ'D     FORMAT 8F10.0
$     (AREA AND DIMENSION VARIABLES      OMIT IF NDVAR1=0)
$   XA(I) .    .    .   XA(NDVAR1)
$         |         |         |         |         |         |         |
       20.0      20.0      20.0       2.0       2.0
$   XAL(I)
$         |         |         |         |         |         |         |
        .50       .50       4.0       .10       .10
$   XAU(I)
$         |         |         |         |         |         |         |
       25.0      35.0      25.0       2.5       4.0
$********1*********2*********3*********4*********5*********6*********7*********
$BLOCK M DESIGN VARIABLE INFORMATION   CARDS AS REQ'D     FORMAT 8F10.0
$     (COORDINATE VARIABLES              OMIT IF NDVAR2=0)
$   XC(I) .    .    .   XC(NDVAR2)
$         |         |         |         |         |         |         |
      150.0      50.0
$   XCL(I)
$         |         |         |         |         |         |         |
        0.0       0.0
$   XCU(I)
$         |         |         |         |         |         |         |
      200.0     100.0
$********1*********2*********3*********4*********5*********6*********7*********
$BLOCK N JOINT DISPLACEMENT CONSTRAINTS    NDSPLC CARDS   FORMAT 3I10,2F10
$     (OMIT IF NDSPLC=0 IN BLOCK B)
$   JN       DIR        LC        BL        BU
$         |         |         |         |         |
          3         2         1      -3.0       3.0
          3         3         2      -3.5       3.5
$********1*********2*********3*********4*********5*********6*********7*********
$BLOCK O FREQUENCY CONSTRAINTS      NO. OF CARDS AS REQ'D      FORMAT 8F10.0
$     (OMIT IF NFREQ=0 IN BLOCK B)
$     FC1  .   . FCN
$         |         |         |         |         |         |         |
        1.0
$********1*********2*********3*********4*********5*********6*********7*********
$BLOCK P END CARD
END
```

TABLE XII

DATA FILE TWO-TIER 3-D PORTAL FRAME

```
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK A TITLE                                1 CARD    FORMAT  80H
 2-TIER FRAME STRUCTURE WITH TRUSS X-BRACES: EXAMPLE 2
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK B CONTROL PARAMETERS                   3 CARDS   FORMAT  8I10
$  NEB       NEF       NJ        NCJ       NMT      IDVCLC     NOJ
$         |         |         |         |         |         |         |
        20        16        12         8         1         2         8
$ NEUBC     LBLCK     NFREQ     NFMASS    NEIG      NEIG1     NPRI
$         |         |         |         |         |         |         |
         1         1         1         4         3         6         0
$  NLC      NOSFLC    NSTRES    NSTW      NFMW
$         |         |         |         |         |
         3        12         2         1         1
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK C DYNAMIC ANALYSIS INFORMATION  1 CARD    FORMAT  I10,2F10.0
$ LMASS     GRAV      EPSEIG
$         |         |         |
         0     386.4        0.
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK D JOINT COORDINATES
$    NJ CARDS                                           FORMAT I10,3F10
$   JN     X-COORD   Y-COORD   Z-COORD
$         |         |         |         |
         1      100.        0.      100.
         2      100.        0.     -100.
         3     -100.        0.     -100.
         4     -100.        0.      100.
         5      100.       50.      100.
         6      100.       50.     -100.
         7     -100.       50.     -100.
         8     -100.       50.      100.
         9      100.      100.      100.
        10      100.      100.     -100.
        11     -100.      100.     -100.
        12     -100.      100.      100.
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK E DESIGN VARIABLE LINKING DATA
$    NCJ CARDS                                          FORMAT 4I10,3F10.0
$   JN       IX        IY        IZ        PCX       PCY       PCZ
$         |         |         |         |         |         |         |
         1         1         0         2       1.0       0.0       1.0
         2         1         0         2       1.0       0.0      -1.0
         3         1         0         2      -1.0       0.0      -1.0
         4         1         0         2      -1.0       0.0       1.0
         5         3         4         5       1.0       1.0       1.0
         6         3         4         5       1.0       1.0      -1.0
         7         3         4         5      -1.0       1.0      -1.0
         8         3         4         5      -1.0       1.0       1.0
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK F MATERIAL PROPERTIES                NMT CARDS   FORMAT  6F10.0
$    E         RHO      SIGMIN    SIGMAX   KEULER     POISSN
$         |         |         |         |         |         |
    2.9E+7       0.3    -42000.    36000.        4.       .27
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK G BAR ELEMENT INFORMATION           NEB CARDS   FORMAT  5I10,F10,I10
$   LNO     NODE2     NODE3     MATCOD    NSDG1     AREA      LSECT
$         |         |         |         |         |         |
         1         1         6         1         1       5.0         1
2,5,2,1,1,5.0,1
3,2,7,1,1,5.0,1
4,6,3,1,1,5.0,1
5,3,8,1,1,5.0,1
6,7,4,1,1,5.0,1
7,4,5,1,1,5.0,1
8,1,8,1,1,5.0,1
9,5,7,1,1,5.0,1
10,6,8,1,1,5.0,1
11,5,10,1,2,5.0,1
12,6,9,1,2,5.0,1
13,6,11,1,2,5.0,1
14,7,10,1,2,5.0,1
```

TABLE XIII

DATA FILE TWO-TIER 3-D PORTAL FRAME continued

```
15,7,12,1,2,5.C,1
16,8,11,1,2,5.C,1
17,8,9,1,2,5.0,1
18,5,12,1,2,5.C,1
19,9,11,1,2,5.C,1
20,10,12,1,2,5.0,1
$*********1*********2*********3*********4*********5*********6*********7*********
$BLCCK H FRAME ELEMENT INFORMATION          2*NEF CARDS FORMAT 7I10/2F10
$   LNC      NOCE2     NCDE3     MATCOC     NSDG1     NSDG2     LSECT
$        |         |         |         |         |         |         |
21,1,5,1,3,4,1
       5.C       0.50
22,2,6,1,3,4,1
       5.0       0.50
23,3,7,1,3,4,1
       5.0       0.50
24,4,8,1,3,4,1
       5.C       0.50
25,5,9,1,5,6,1
       5.0       0.50
26,6,1C,1,5,6,1
       5.0       0.50
27,7,11,1,5,6,1
       5.C       C.50
28,8,12,1,5,6,1
       5.0       0.50
29,5,6,1,7,8,1
       5.0       0.50
30,6,7,1,7,8,1
       5.C       C.50
31,7,8,1,7,8,1
       5.0       0.50
32,8,5,1,7,8,1
       5.0       0.50
33,9,1C,1,9,1C,1
       5.C       C.50
34,10,11,1,9,1C,1
       5.C       0.50
35,11,12,1,9,1C,1
       5.0       0.50
36,12,9,1,9,1C,1
       5.C       C.5C
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK I JOINT CCNSTPAINT DATA          NCJ CARDS    FORMAT  7I10
$   JN       IX        IY        IZ        IXX       IYY       IZZ
$        |         |         |         |         |         |         |
1,1,1,1,1,1,1
2,1,1,1,1,1,1
3,1,1,1,1,1,1
4,1,1,1,1,1,1
5,
6,
7,
8,
9,
10,
11,
12,
$*********1*********2*********3*********4*********5*********6*********7*********
$BLCCK J JCINT LCACING CATA             1 CARO       FORMAT I10
$     (CMIT IF NLC=0 IN BLCCK B)
$   NLJ
$        |
2,
$                                       NLJ CARDS    FORMAT  I10,6F10
$   JN       FX        FY        FZ        TX        TY        TZ
$        |         |         |         |         |         |         |
9,1000.
1C,1000.
4,
9,500.
10,500.
```

TABLE XIV

DATA FILE TWO-TIER 3-D PORTAL FRAME continued

```
5,-500.
6,-500.
4,
10,1000.
9,0.0,0.0,1000.
12,-1000.
11,0.0,0.0,-1000.
$********1*********2*********3*********4*********5*********6*********7*********
$BLOCK K FIXED MASS DATA         NFMASS CARDS    FORMAT I10,F10.0
$     (OMIT IF NFMASS=0 IN BLOCK B)
$    JN        MASS
$          |         |
9,50.0
10,50.0
11,50.0
12,50.0
$********1*********2*********3*********4*********5*********6*********7*********
$BLOCK L DESIGN VARIABLE INFORMATION  CARDS AS REQ'D     FORMAT 8F10.0
$     (AREA AND DIMENSION VARIABLES      OMIT IF NDVAR1=0)
$    XA(I) .  .  .   XA(NDVAR1)
$         |         |         |         |         |         |         |
      3.5       3.5       5.0       0.5       5.0       0.5       5.0       0.5
      5.0       0.5
$    XAL(I)
$         |         |         |         |         |         |         |
      0.1       0.1       .50       0.1       .50       0.1       .50       0.1
      .50       0.1
$    XAU(I)
$         |         |         |         |         |         |         |
     30.0      30.0      30.0       .50      30.0       .50      30.0       0.5
     30.0       .50
$********1*********2*********3*********4*********5*********6*********7*********
$BLOCK M DESIGN VARIABLE INFORMATION  CARDS AS REQ'D     FORMAT 8F10.0
$     (COORDINATE VARIABLES            OMIT IF NDVAR2=0)
$    XC(I) .  .  .   XC(NDVAR2)
$         |         |         |         |         |         |         |
    100.0     100.0     100.0     100.0      50.0
$    XCL(I)
$         |         |         |         |         |         |         |
     20.0      20.0      20.0      20.0      20.0
$    XCU(I)
$         |         |         |         |         |         |         |
    160.0     160.0     160.0     160.0      80.0
$********1*********2*********3*********4*********5*********6*********7*********
$BLOCK N JOINT DISPLACEMENT CONSTRAINTS    NDSPLC CARDS   FORMAT 3I10,2F10
$     (OMIT IF NDSPLC=0 IN BLOCK B)
$    JN        DIR       LC        BL        BU
$         |         |         |         |         |
         9         1         1      -5.0       5.0
        10         1         1      -5.0       5.0
        11         1         1      -5.0       5.0
        12         1         1      -5.0       5.0
         9         1         2      -5.0       5.0
        10         1         2      -5.0       5.0
        11         1         2      -5.0       5.0
        12         1         2      -5.0       5.0
         9         3         3      -5.0       5.0
        10         1         3      -5.0       5.0
        11         3         3      -5.0       5.0
        12         1         3      -5.0       5.0
$********1*********2*********3*********4*********5*********6*********7*********
$BLOCK O FREQUENCY CONSTRAINTS      NO. OF CARDS AS REQ'D     FORMAT 8F10.0
$     (OMIT IF NFREQ=0 IN BLOCK B)
$      FC1  .  . FCN
$         |         |         |         |         |         |         |
      1.0       5.0      10.0
$********1*********2*********3*********4*********5*********6*********7*********
$BLOCK P END CARD
END
```

TABLE XV

DATA FILE DD-963 FOREMAST

```
$BLOCK A TITLE
DD-963 CLASS DESTROYER FORWARD MAST REDESIGN: EXAMPLE 1
$   THIS IS A SIMPLIFICATION  OF THE ACTUAL STRUCTURE AND LOADS BASED ON
$   NAVSHIPS DRAWING NUMBER 128-4539510 AND NAVSHIPS SKETCH NUMBER
$   80064-128-SK4587979
$   THIS ANALYSIS REQUIRES A THE X-AXIS FORWARD, Y-AXIS UP, AND Z-AXIS
$   TO STBD; A DIFFERENT ORIENTATION THAN IN THE ABOVE DRAWINGS
$BLOCK B CONTROL PARAMETERS
$   NEB       NEF        NJ        NCJ       NMT      IDVCLC      NDJ
$         |         |         |         |         |         |         |
          0       172        73        20         1         1         0
$ NEUBC      LBLCK      NFREQ     NFMASS     NEIG      NEIG1      NPRI
$         |         |         |         |         |         |         |
          1         1         0        33         0         0         0
$   NLC      NDSFLC     NSTRES     NSTW      NFMW
$         |         |         |         |         |
          1        11         2         1         1
$********1*********2*********3*********4*********5*********6*********7***
$BLOCK C DYNAMIC ANALYSIS INFORMATION
          0     386.4        0.
$BLOCK C JOINT COORDINATES
          1    -240.0        0.0    -106.0
          2    -240.0        0.0     106.0
          3       0.0        0.0      42.0
          4       0.0        0.0     -42.0
          5    -228.0       54.0       0.0
          6    -120.0       54.0      68.4
          7     -2.64       54.0       0.0
          8    -120.0       54.0     -68.4
          9    -216.0      108.0     -94.7
         10    -216.0      108.0      94.7
         11     -5.28      108.0      42.0
         12     -5.28      108.0     -42.0
         13     -7.92      162.0       0.0
         14    -172.0      444.0       0.0
$ NODE 15 IS AN UNCONNECTED FIXED DUMMY NODE
         15       0.1        0.0       0.0
         16    -192.6      216.0    -83.16
         17    -192.6      216.0     83.16
         18    -10.56      216.0      42.0
         19      54.0      216.0      42.0
         20      54.0      216.0     -42.0
         21    -10.56      216.0     -42.0
         22    -172.0      736.0     -18.0
         23    -172.0      736.0      18.0
         24     -13.2      270.0       0.0
         25    -168.8      324.0       0.0
         26    -168.8      324.0    -71.76
         27    -168.8      324.0     71.76
         28    -15.84      324.0      42.0
         29    -15.84      324.0     -42.0
         30     108.0      324.0      48.0
         31     168.0      324.0       0.0
         32     108.0      324.0     -48.0
         33    -18.12      372.0       0.0
         34    -147.8      420.0    -61.68
         35    -147.8      420.0       0.0
         36    -147.8      420.0     61.68
         37     -20.4      420.0      42.0
         38      12.0      420.0      39.0
         39     -20.4      420.0     -42.0
         40      12.0      420.0     -39.0
         41     -22.2      456.0       0.0
         42    -132.0      492.0     -54.0
         43    -132.0      492.0      54.0
         44    -172.0      492.0     -54.0
         45     -24.0      492.0      42.0
         46      30.0      492.0      36.0
         47     -24.0      492.0     -42.0
         48      30.0      492.0     -36.0
$ END NODES FOR THE LOWER QUADRAPOD OF THE FORWARD MAST
$ START THE UPPER FOREMAST NODES
```

TABLE XVI

DATA FILE DD-963 FOREMAST continued

```
             49     -172.0      492.0     -120.0
             50     -172.0      492.0      120.0
             51     -228.0      408.0        0.0
             52     -288.0      492.0      -56.0
             53     -288.0      492.0       56.0
             54     -240.0      492.0        0.0
             55     -172.0      492.0     -276.0
             56     -172.0      492.0      276.0
             57     -218.0      600.0      -24.0
             58     -218.0      600.0       24.0
             59     -172.0      492.0       54.0
$ NODE 60 IS AN UNCONNECTED FIXED DUMMY NODE
             60        0.0        0.0        0.0
             61     -172.0      600.0        0.0
             62     -172.0      492.0        0.0
             63     -172.0      664.0        0.0
             64     -172.0      736.0        0.0
             65     -172.0      896.0        0.0
             66     -172.0      976.0        0.0
             67     -172.0     1056.0        0.0
             68     -172.0      736.0     -264.0
             69     -172.0      736.0      264.0
             70     -172.0      736.0     -156.0
             71     -172.0      736.0      156.0
             72     -172.0      736.0     -228.0
             73     -172.0      736.0      228.0
$*********1*********2*********3*********4*********5*********6*********7***
$BLOCK F MATERIAL INFORMATION
     2.9E+7       0.1    -42000.    42000.        4.       .27
$*********1*********2*********3*********4*********5*********6*********7***
$BLOCK G BAR ELEMENT INFORMATION       NEB CARDS    FORMAT  5I10,F10,I10
$    LNO      NODE2      NODE3    MATCOD     NSDG1      AREA      LSECT
$        |         |         |         |         |         |         |
$*********1*********2*********3*********4*********5*********6*********7***
$BLOCK H FRAME ELEMENT INFORMATION
$ START FRAME ELEMENTS FOR 1ST OR LOWEST TIER OF QUADRAPOD
         1         4        12         1         1         2         1
     11.75       .75
         2         3        11         1         1         2         1
     11.75       .75
         3         1         9         1         1         2         1
     11.75       .75
         4         2        10         1         1         2         1
     11.75       .75
         5         4         8         1         3         4         1
     7.625      .375
         6         3         6         1         3         4         1
     7.625      .375
         7         1         8         1         3         4         1
     7.625      .375
         8         2         6         1         3         4         1
     7.625      .375
         9         8        12         1         3         4         1
     7.625      .375
        10         6        11         1         3         4         1
     7.625      .375
        11         8         9         1         3         4         1
     7.625      .375
        12         6        10         1         3         4         1
     7.625      .375
        13         3         7         1         3         4         1
     7.625      .375
        14         4         7         1         3         4         1
     7.625      .375
        15         7        11         1         3         4         1
     7.625      .375
        16         7        12         1         3         4         1
     7.625      .375
        17         1         5         1         3         4         1
     7.625      .375
        18         2         5         1         3         4         1
     7.625      .375
```

TABLE XVII

DATA FILE DD-963 FOREMAST continued

```
      19        5       9      1      3      4      1
   7.625     .375
      20        5      10      1      3      4      1
   7.625     .375
      21       12       9      1      3      4      1
   7.625     .375
      22       11      10      1      3      4      1
   7.625     .375
      23       11      12      1      3      4      1
   7.625     .375
      24        9      10      1      3      4      1
   7.625     .375
$ END 1ST TIER OF QUADRAPOD START 2ND TIER
      25       12      21      1      1      2      1
   11.75      .75
      26       11      18      1      1      2      1
   11.75      .75
      27        9      16      1      1      2      1
   11.75      .75
      28       10      17      1      1      2      1
   11.75      .75
      29        9      21      1      5      6      1
   7.625     .375
      30       10      18      1      5      6      1
   7.625     .375
      31       11      13      1      5      6      1
   7.625     .375
      32       12      13      1      5      6      1
   7.625     .375
      33       13      18      1      5      6      1
   7.625     .375
      34       13      21      1      5      6      1
   7.625     .375
      35       10      16      1      5      6      1
   7.625     .375
      36       21      16      1      7      8      1
   7.625     .375
      37       17      18      1      7      8      1
   7.625     .375
      38       18      21      1      7      8      1
   7.625     .375
      39       16      17      1      7      8      1
   7.625     .375
      40       12      20      1      7      8      1
  11.625     .375
      41       11      19      1      7      8      1
  11.625     .375
      42       20      21      1      7      8      1
   7.625     .375
      43       18      19      1      7      8      1
   7.625     .375
      44       19      20      1      7      8      1
   7.625     .375
$ END THE 2ND TIER OF THE QUADRAPOD START THE 3RD TIER
      45       21      29      1      1      2      1
   11.75      .75
      46       18      28      1      1      2      1
   11.75      .75
      47       16      26      1      1      2      1
   11.75      .75
      48       17      27      1      1      2      1
   11.75      .75
      49       16      29      1      9     10      1
   7.625     .375
      50       17      28      1      9     10      1
   7.625     .375
      51       20      32      1      7      8      1
  11.625     .375
      52       19      30      1      7      8      1
  11.625     .375
      53       20      31      1      9     10      1
   7.625     .375
```

TABLE XVIII

DATA FILE DD-963 FOREMAST continued

```
        54        19        31        1        9        10        1
     7.625      .375
        55        18        24        1        9        10        1
     7.625      .375
        56        21        24        1        9        10        1
     7.625      .375
        57        24        28        1        9        10        1
     7.625      .375
        58        24        29        1        9        10        1
     7.625      .375
        59        16        25        1        9        10        1
     11.50       .50
        60        17        25        1        9        10        1
     11.50       .50
$ MEMBERS 61 THRU 70 MODEL THE SPQ-9 PLATFORM ALONG WITH A FIXED MASS
        61        26        29        1       11        12        1
     11.50       .50
        62        27        28        1       11        12        1
     11.50       .50
        63        29        32        1       11        12        1
     11.50       .50
        64        28        30        1       11        12        1
     11.50       .50
        65        31        32        1       11        12        1
     11.50       .50
        66        31        30        1       11        12        1
     11.50       .50
        67        28        29        1       11        12        1
     11.50       .50
$ ELEMENTS 68 AND 69 ARE DUMMY ELEMENTS
        68        15        60        1        0         0        1
      .001     .0001
        69        15        60        1        0         0        1
      .001     .0001
        70        30        32        1       11        12        1
     11.50       .50
$ END THE 3RD TIER OF THE QUADRAPOD START THE 4TH TIER
        71        29        39        1        1         2        1
     11.75       .75
        72        28        37        1        1         2        1
     11.75       .75
        73        26        34        1        1         2        1
     11.75       .75
        74        27        36        1        1         2        1
     11.75       .75
        75        26        39        1       13        14        1
     7.625      .375
        76        27        37        1       13        14        1
     7.625      .375
        77        29        40        1       13        14        1
     7.625      .375
        78        28        38        1       13        14        1
     7.625      .375
        79        26        52        1       13        14        1
     7.625      .375
        80        27        53        1       13        14        1
     7.625      .375
        81        28        33        1       13        14        1
     7.625      .375
        82        29        33        1       13        14        1
     7.625      .375
        83        33        37        1       13        14        1
     7.625      .375
        84        33        39        1       13        14        1
     7.625      .375
        85        34        39        1       13        14        1
     7.625      .375
        86        36        37        1       13        14        1
     7.625      .375
        87        39        40        1       13        14        1
     7.625      .375
        88        37        38        1       13        14        1
```

TABLE XIX

DATA FILE DD-963 FOREMAST continued

```
        7.625      .375
          124        53       54       1       15       16       1
        7.625      .375
          125        42       54       1       15       16       1
        7.625      .375
          126        43       54       1       15       16       1
        7.625      .375
          127        42       44       1       15       16       1
        7.625      .375
          128        43       59       1       15       16       1
        7.625      .375
$ END THE LOWER QUADRAPOD START THE TOPMAST MEMBERS
          129        52       58       1       17       18       1
        7.625      .375
          130        52       57       1       17       18       1
        7.625      .375
          131        53       58       1       17       18       1
        7.625      .375
          132        57       61       1       17       18       1
        7.625      .375
          133        58       61       1       17       18       1
        7.625      .375
          134        57       58       1       17       18       1
        7.625      .375
          135        57       63       1       17       18       1
        7.625      .375
          136        58       63       1       17       18       1
        7.625      .375
          137        14       25       1       19       20       1
        23.00       1.5
          138        14       62       1       19       20       1
        23.00       1.5
          139        62       61       1       19       20       1
        23.00       1.5
          140        61       63       1       19       20       1
        23.00       1.5
          141        63       64       1       19       20       1
        23.00       1.5
          142        64       65       1       21       22       1
         9.50       .50
          143        65       66       1       21       22       1
         9.50       .50
          144        66       67       1       21       22       1
         9.50       .50
          145        37       39       1       13       14       1
        7.625      .375
$ UPPER YARDARMS AND BRACES
          146        64       70       1       23       24       1
        14.00       .75
          147        64       71       1       23       24       1
        14.00       .75
          148        70       72       1       25       26       1
        10.00       .50
          149        71       73       1       25       26       1
        10.00       .50
          150        72       68       1       25       26       1
        10.00       .50
          151        73       69       1       25       26       1
        10.00       .50
          152        61       72       1       27       28       1
        7.625      .375
          153        61       73       1       27       28       1
        7.625      .375
          154        63       70       1       29       30       1
         5.75       .25
          155        63       71       1       29       30       1
         5.75       .25
          156        61       72       1       27       28       1
        7.625      .375
          157        61       73       1       27       28       1
        7.625      .375
          158        63       70       1       29       30       1
```

TABLE XX

DATA FILE DD-963 FOREMAST continued

```
       7.625        .375
$ END THE 4RD TIER CF THE CUADRAPOC START THE 5TH TIER
          89          35          47          1          1          2          1
       11.75         .75
          90          37          45          1          1          2          1
       11.75         .75
          91          34          42          1          1          2          1
       11.75         .75
          92          36          43          1          1          2          1
       11.75         .75
          93          34          47          1         15         16          1
       7.625        .375
          94          36          45          1         15         16          1
       7.625        .375
          95          40          48          1         13         14          1
       7.625        .375
          96          38          46          1         13         14          1
       7.625        .375
          97          28          26          1         13         14          1
       7.625        .375
          98          25          27          1         13         14          1
       7.625        .375
          99          26          35          1         13         14          1
       7.625        .375
         100          27          35          1         13         14          1
       7.625        .375
         101          34          35          1         13         14          1
       7.625        .375
         102          35          36          1         13         14          1
       7.625        .375
         103          35          42          1         13         14          1
       7.625        .375
         104          35          43          1         13         14          1
       7.625        .375
         105          37          41          1         13         14          1
       7.625        .375
         106          39          41          1         13         14          1
       7.625        .375
         107          41          45          1         13         14          1
       7.625        .375
         108          41          47          1         13         14          1
       7.625        .375
$ MEMBERS 109 THRU 128 MODEL THE SPG-60 PLATFORM ALONG WITH A FIXED MASS
         109          42          47          1         15         16          1
       7.625        .375
         110          43          45          1         15         16          1
       7.625        .375
         111          42          43          1         15         16          1
       7.625        .375
         112          45          47          1         15         16          1
       7.625        .375
         113          48          47          1         15         16          1
       7.625        .375
         114          45          46          1         15         16          1
       7.625        .375
         115          48          46          1         15         16          1
       7.625        .375
         116          52          53          1         15         16          1
       7.625        .375
         117          26          51          1         13         14          1
       7.625        .375
         118          27          51          1         13         14          1
       7.625        .375
         119          52          51          1         13         14          1
       7.625        .375
         120          53          51          1         13         14          1
       7.625        .375
         121          44          52          1         15         16          1
       7.625        .375
         122          53          59          1         15         16          1
       7.625        .375
         123          52          54          1         15         16          1
```

TABLE XXI

DATA FILE DD-963 FOREMAST continued

```
      5.75        .25
       159         63        71         1        29        30         1
      5.75        .25
$ SPS55 PLATFORM
       160         63        22         1        29        30         1
      5.75        .25
       161         63        23         1        29        30         1
      5.75        .25
       162         22        23         1        29        30         1
      5.75        .25
       163         64        23         1        29        30         1
      5.75        .25
       164         64        22         1        29        30         1
      5.75        .25
$ LOWER YARDARM AND BRACES
       165         44        62         1        15        16         1
     7.625       .375
       166         59        62         1        15        16         1
     7.625       .375
       167         49        44         1        31        32         1
     11.50        .50
       168         59        50         1        31        32         1
     11.50        .50
       169         49        55         1        31        32         1
     11.50        .50
       170         50        56         1        31        32         1
     11.5C        .5C
       171         14        49         1        33        34         1
      5.75        .25
       172         14        50         1        33        34         1
      5.75        .25
$*********1*********2*********3*********4*********5*********6*********7***
$BLOCK I JOINT CONSTRAINT DATA         NCJ CARDS     FORMAT  7I10
$   JN        IX        IY        IZ       IXX       IYY       IZZ
$
         1         1         1         1         1         1         1
         2         1         1         1         1         1         1
         3         1         1         1         1         1         1
         4         1         1         1         1         1         1
         5         0         0         0         0         0         0
         6         C         0         0         0         0         0
         7         0         0         0         0         0         0
         8         0         0         0         0         0         0
         9         C         0         0         0         0         0
        10         0         0         0         0         0         0
        11         0         0         0         0         0         0
        12         C         0         0         0         0         0
        13         0         0         0         0         0         0
        14         0         0         0         0         0         0
        15         1         1         1         1         1         1
        16         0         0         0         0         0         0
        17         0         0         0         0         0         0
        18         0         0         0         0         0         0
        19         0         0         0         0         0         0
        20         0         0         0         0         0         0
        21         C         0         0         0         0         0
        22         0         0         0         0         0         0
        23         0         0         0         0         0         0
        24         0         0         0         0         0         0
        25         0         0         0         0         0         0
        26         0         0         0         0         0         0
        27         0         0         0         0         0         0
        28         0         0         0         0         0         0
        29         0         0         0         0         0         0
        30         C         0         0         0         0         0
        31         0         0         0         0         0         0
        32         0         0         0         0         0         0
        33         0         0         0         0         0         0
        34         0         0         0         0         0         0
        35         0         0         0         0         0         0
        36         0         0         0         0         0         0
        37         0         0         0         0         0         0
```

TABLE XXII

DATA FILE DD-963 FOREMAST continued

```
        38         0         0         0         0         0         0
        39         0         0         0         0         0         0
        40         0         0         0         0         0         0
        41         0         0         0         0         0         0
        42         0         0         0         0         0         0
        43         0         0         0         0         0         0
        44         0         0         0         0         0         0
        45         0         0         0         0         0         0
        46         0         0         0         0         0         0
        47         0         0         0         0         0         0
        48         0         0         0         0         0         0
        49         0         0         0         0         0         0
        50         0         0         0         0         0         0
        51         0         0         0         0         0         0
        52         0         0         0         0         0         0
        53         0         0         0         0         0         0
        54         0         0         0         0         0         0
        55         0         0         0         0         0         0
        56         0         0         0         0         0         0
        57         0         0         0         0         0         0
        58         0         0         0         0         0         0
        59         0         0         0         0         0         0
        60         1         1         1         1         1         1
        61         0         0         0         0         0         0
        62         0         0         0         0         0         0
        63         0         0         0         0         0         0
        64         0         0         0         0         0         0
        65         0         0         0         0         0         0
        66         0         0         0         0         0         0
        67         0         0         0         0         0         0
        68         0         0         0         0         0         0
        69         0         0         0         0         0         0
        70         0         0         0         0         0         0
        71         0         0         0         0         0         0
        72         0         0         0         0         0         0
        73         0         0         0         0         0         0
$********1*********2*********3*********4*********5*********6*********7***
$BLOCK J JOINT LOADING DATA              1 CARD    FORMAT I10
$     (OMIT IF NLC=0 IN BLOCK 8)
$   NLJ
$         |
        76
$                                        NLJ CARDS    FORMATI10,6F10
$    JN        FX        FY        FZ        TX        TY        TZ
$ HALYARD AND WIRE ANTENNA LOADS
$         |         |         |         |         |         |         |
        49      -50.    -100.0       0.0        0.        0.        0.
        50      -50.    -100.0       0.0        0.        0.        0.
        55      -50.    -100.0       0.0        0.        0.        0.
        56      -50.    -100.0       0.0        0.        0.        0.
        67        0.     -50.0       0.0        0.        0.        0.
$ SHIP'S MOTION LOADS
$    JN        FX        FY        FZ        TX        TY        TZ
$         |         |         |         |         |         |         |
         1       0.0       0.0     160.5       0.0       0.0       0.0
         2       0.0       0.0     163.3       0.0       0.0       0.0
         3       0.0       0.0      96.4       0.0       0.0       0.0
         4       0.0       0.0     137.5       0.0       0.0       0.0
         5       0.0       0.0     108.2       0.0       0.0       0.0
         6       0.0       0.0     184.3       0.0       0.0       0.0
         7       0.0       0.0      66.7       0.0       0.0       0.0
         8       0.0       0.0     184.3       0.0       0.0       0.0
         9       0.0       0.0     414.9       0.0       0.0       0.0
        10       0.0       0.0     467.0       0.0       0.0       0.0
        11       0.0       0.0     381.6       0.0       0.0       0.0
        12       0.0       0.0     381.6       0.0       0.0       0.0
        13       0.0       0.0      70.2       0.0       0.0       0.0
        14       0.0       0.0     325.4       0.0       0.0       0.0
        16       0.0       0.0     565.7       0.0       0.0       0.0
        17       0.0       0.0     528.5       0.0       0.0       0.0
        18       0.0       0.0     429.1       0.0       0.0       0.0
        19       0.0       0.0     226.9       0.0       0.0       0.0
```

TABLE XXIII

DATA FILE DD-963 FOREMAST continued

```
        20        0.0       0.0     214.8       0.0       0.0       0.0
        21        0.0       0.0     468.9       0.0       0.0       0.0
        22        0.0       0.0     539.0       0.0       0.0       0.0
        23        0.0       0.0     539.0       0.0       0.0       0.0
        24        0.0       0.0      91.6       0.0       0.0       0.0
        25        0.0       0.0     474.7       0.0       0.0       0.0
        26        0.0       0.0    3234.2       0.0       0.0       0.0
        27        0.0       0.0    2296.2       0.0       0.0       0.0
        28        0.0       0.0    1874.0       0.0       0.0       0.0
        29        0.0       0.0    1874.0       0.0       0.0       0.0
        30        0.0       0.0    1459.2       0.0       0.0       0.0
        31        0.0       0.0    1238.5       0.0       0.0       0.0
        32        0.0       0.0    1489.9       0.0       0.0       0.0
        33        0.0       0.0     211.7       0.0       0.0       0.0
        34        0.0       0.0     498.7       0.0       0.0       0.0
        35        0.0       0.0     606.8       0.0       0.0       0.0
        36        0.0       0.0     498.7       0.0       0.0       0.0
        37        0.0       0.0     725.9       0.0       0.0       0.0
        38        0.0       0.0     174.3       0.0       0.0       0.0
        39        0.0       0.0     725.9       0.0       0.0       0.0
        40        0.0       0.0     174.3       0.0       0.0       0.0
        41        0.0       0.0     345.5       0.0       0.0       0.0
        42        0.0       0.0    1729.0       0.0       0.0       0.0
        43        0.0       0.0    1729.0       0.0       0.0       0.0
        44        0.0       0.0    1425.6       0.0       0.0       0.0
        45        0.0       0.0    1810.4       0.0       0.0       0.0
        46        0.0       0.0    1468.1       0.0       0.0       0.0
        47        0.0       0.0    1810.4       0.0       0.0       0.0
        48        0.0       0.0    1468.1       0.0       0.0       0.0
        49        0.0       0.0     185.6       0.0       0.0       0.0
        50        0.0       0.0     185.6       0.0       0.0       0.0
        51        0.0       0.0     540.9       0.0       0.0       0.0
        52        0.0       0.0     965.8       0.0       0.0       0.0
        53        0.0       0.0     783.4       0.0       0.0       0.0
        54        0.0       0.0     464.2       0.0       0.0       0.0
        55        0.0       0.0     113.0       0.0       0.0       0.0
        56        0.0       0.0     113.0       0.0       0.0       0.0
        57        0.0       0.0     294.5       0.0       0.0       0.0
        58        0.0       0.0     436.2       0.0       0.0       0.0
        59        0.0       0.0    1425.6       0.0       0.0       0.0
        61        0.0       0.0     733.8       0.0       0.0       0.0
        62        0.0       0.0     304.6       0.0       0.0       0.0
        63        0.0       0.0     544.0       0.0       0.0       0.0
        64        0.0       0.0    1407.7       0.0       0.0       0.0
        65        0.0       0.0     135.0       0.0       0.0       0.0
        66        0.0       0.0     138.8       0.0       0.0       0.0
        67        0.0       0.0     100.3       0.0       0.0       0.0
        68        0.0       0.0      60.1       0.0       0.0       0.0
        69        0.0       0.0      60.1       0.0       0.0       0.0
        70        0.0       0.0     463.2       0.0       0.0       0.0
        71        0.0       0.0    1713.1       0.0       0.0       0.0
        72        0.0       0.0     237.0       0.0       0.0       0.0
        73        0.0       0.0    1081.2       0.0       0.0       0.0
$*********1*********2*********3*********4*********5*********6*********7***
$BLOCK K FIXED MASS DATA          NFMASS CARDS   FORMAT I10,F10.0
$     (OMIT IF NFMASS=0 IN BLOCK 8)
$    JN        MASS
$         |         |
$    PLATFORM BELOW SPQ-9
        18      32.0
        19      32.0
        20      32.0
        21      32.0
$    SPQ-9 AND PLATFORM
        26     890.0
        27     890.0
        28     890.0
        29     890.0
        30     890.0
        31     890.0
        32     890.0
$    SPG-60 AND PLATFORM
```

```
         42        940.0
         43        940.0
         44        940.0
         45        940.0
         46        940.0
         47        940.0
         48        940.0
         55        940.0
$    SPS-55 AND PLATFORM
         22        325.0
         23        325.0
         64        325.0
$    ANTENNAS AND OTHER FIXTURES
         49         25.0
         50         25.0
         55         12.0
         56         12.0
         64        220.0
         67         30.0
         68         26.0
         69         26.0
         70        120.0
         71        972.0
         73        965.0
$*********1*********2*********3*********4*********5*********6*********7***
$BLOCK L DESIGN VARIABLE INFORMATION  CARDS AS REQ'D    FORMAT 8F10.0
$     (AREA AND DIMENSION VARIABLES      OMIT IF NDVAR1=0)
$    XA(I) .   .   .   XA(NDVAR1)
$         |         |         |         |         |         |         |
     13.75       .75     7.625      .375     8.625      .375     7.625      .375
     8.625      .375     12.50       .50     7.625      .375     7.625      .375
     7.625      .375     23.00      1.50      9.50       .50     14.00       .75
     10.00       .50     7.625      .375     7.625      .375     11.50       .50
      5.75       .25
$    XAL(I)
$         |         |         |         |         |         |         |
      8.00       .50     5.000      .250     5.000      .250     5.000      .250
     5.000      .250      8.00       .25     5.000      .250     5.000      .250
     5.000      .250     15.00       .50      6.00       .25     10.00       .50
      6.00       .25     5.000      .250      3.00       .10      8.00       .25
      3.00       .10
$    XAU(I)
$         |         |         |         |         |         |         |
     22.00      2.50     15.00      1.50     15.00      1.50     15.00      1.50
     15.00      1.50     22.00      2.50     15.00      1.50     15.00      1.50
     15.00      1.50     36.00      2.50     15.00      1.50     26.00      2.00
     15.00      1.50     15.00      1.50     12.00      1.50     22.00      1.50
     12.00      1.50
$*********1*********2*********3*********4*********5*********6*********7***
$BLOCK N JOINT DISPLACEMENT CONSTRAINTS   NDSPLC CARDS  FORMAT 3I10,2F10
$     (OMIT IF NDSPLC=0 IN BLOCK B)
$    JN        DIR        LC        BL        BU
$         |         |         |         |         |
         67         1         1      -6.0       6.0
         67         3         1      -6.0       6.0
         46         3         1      -3.0       3.0
         48         3         1      -3.0       3.0
         22         1         1      -6.0       6.0
         22         3         1      -6.0       6.0
         23         1         1      -6.0       6.0
         23         3         1      -6.0       6.0
         64         5         1      -.02       .02
         31         2         1      -2.0       2.0
         31         5         1      -.02       .02
$*********1*********2*********3*********4*********5*********6*********7***
$BLOCK O FREQUENCY CONSTRAINTS
$       2.0
$*********1*********2*********3*********4*********5*********6*********7***
$BLOCK P END CARD
END
```

APPENDIX B

PROGRAM ORGANIZATION

A. DESCRIPTION

The program organization is layed out in the following flow charts. The main driver program (SADXM) calls a subdriver (SADXSD), and the optimizer of the user's choice. All changes required for replacement of the optimizer are made in SADXM, thus allowing for easy testing of several optimizers on the same problem.

SADXSD may be called from the main for input, analysis, and output. Printed output may vary as the user requires. A complete listing of all subroutines and their functions is given in Table XXIV.

TABLE XXIV

SUBROUTINE DIRECTORY

SADXM	DRIVER PROGRAM FOR USING THE ABOVE SUBROUTINES. SADXM MAY BE COUPLED TO OPTIMIZER OF USER'S CHOICE.
SADXSD	SUBDRIVER PROGRAM FOR COUPLING SADX ROUTINES TO SADXM
SADX01	THIS ROUTINE READS AND PRINTS INPUT DATA AND ORGANIZES PSEUDO-DYNAMIC STORAGE ALLOCATION
SADX02	BUILDS VECTORS JC AND IIK FOR FINITE ELEMENT STRUCTURAL ANALYSIS
SADX03	BUILDS THE 12x12 ELEMENT STIFFNESS MATRIX
SADX05	SUPERIMPOSES THE ELEMENT STIFFNESS MATRIX EK (OR ELEMENT MASS MATRIX EM) ON THE COMPACTED GLOBAL STIFFNESS MATRIX AK (OR THE GLOBAL COMPACTED MASS MATRIX AM)
SADX06	BUILDS GLOBAL LUMPED MASS MATRIX
SADX07	LU DECOMPOSES SYMMETRIC,POSITIVE-DEFINITE SPARCE MATRICES,THE UPPER TRIANGLE OF WHICH IS STORED IN MATRIX AK (OR AM) WITH LEADING ZEROES NOT STORED
SADX08	FORWARD AND BACK SUBSTITUTES TO YIELD A SOLUTION A SET OF LINEAR EQUATIONS (DECOMPOSED BY SADX07 OR EQUIVALENT)
SADX09	PRINTS ALL JOINT DISPLACEMENTS FOR EACH LOAD CONDITION OF A FINITE ELEM. STRUCTURE
SADX11	ROUTINE TO ORGANIZE ANALYSIS
SADX15	CALCULATES VALUES FOR ALL DESIGN AND BEHAVIORIAL CONSTRAINTS AS DEFINED BY "SADX" PROGRAM
SADX16	CALCULATES STRESS IN TRUSS ELEMENT LNO UNDER LOAD CONDITION JJ
SADX17	PRINTS STRESSES AND/OR FORCES FOR TRUSS ELEMENTS
SADX19	ADDS ELEMENT MASS MATRIX AA OF ELEMENT LNO TO GLOBAL MASS MATRIX AM TO BUILD THE LUMPED MASS MATRIX
SADX23	CALCULATES WEIGHT OF TRUSS/FRAME STRUCTURE OR CALCULATE WEIGHT OF INDIVIDUAL MEMBERS
SADX36	CALCULATES (XEIG-T*AM*XEIG) FOR GRADIENT CALCULATIONS IN FREQUENCY CONSTRAINTS
SADX37	CALCULATES EIGENVALUE GRADIENT INFORMATION IN FINITE ELEMENT STRUCTURAL ANALYSIS AND DESIGN

SADX46	READS INPUT INFORMATION FOR TRUSS ELEMENTS
SADX47	TRANSFORMS THE ELEMENT STIFFNESS MATRIX EK (OR ELEMENT MASS MATRIX EM) FROM LOCAL TO GLOBAL COORDINATES
SADX49	SOLVES REAL EIGENVALUE PROBLEMS USING THE SUBSPACE ITERATION METHOD
SADX50	BUILDS INITIAL SET OF BASIS VECTORS FOR EIGENSOLUTION BY REDUCED BASIS METHOD
SADX53	PRINTS MEMBER INFORMATION FOR TRUSS ELEMENTS
SADX62	PRINTS NEIG EIGENVALUES STORED IN EIGVAL, AND THEIR CORRESPONDING EIGENVECTORS STORED IN XEIG
SADX71	PRINTS G VECTOR OF CONSTRAINTS
SADX72	READS IN FRAME ELEMENT INPUT DATA
SADX78	BUILDS 3x3 TRANSFORMATION ARRAY TRFORM FOR TRANSFORMING FROM LOCAL TO GLOBAL COORDINATES
SADX80	CALLS SADX03 TO BUILD THE ELEMENT STIFFNESS MATRIX; CALLS SADX47 TO TRANSFORM THE MATRIX; AND CALLS SADX05 TO BUILD THE REDUCED GLOBAL STIFFNESS MATRIX
SADX81	CALCULATES STRESS IN FRAME ELEMENT LNO UNDER LOAD CONDITION JJ (IF JJ=0 STRESSES CALCULATED FOR ALL LOAD CONDITIONS)
SADX82	READS INPUT DATA FOR FRAME ELEMENTS WITH SPECIFIED SECTION TYPES
SADX83	PRINTS STRESSES AND/OR FORCES FOR FRAME ELEMENTS
SADX84	PRINTS MEMBER INFORMATION FOR FRAME ELEMENTS
SADX85	CALCULATES SECTION PROPERTIES FOR FRAME ELEMENTS OF A SECTION TYPE GIVEN BY ISECT
SADX86	CALLS EITHER SADX06 TO BUILD THE LUMPED MASS MATRIX OR BUILDS THE CONSISTENT MASS MATRIX BY CALLING SADX87 TO BUILD THE ELEMENT MASS MATRIX, SADX78 TO BUILD THE TRANSFORMATION MATRIX, SADX47 TO TRANSFORM THE ELEMENT MASS MATRIX, AND SADX88 TO ASSEMBLE THE COMPACTED GLOBAL MASS MATRIX
SADX87	CALLS BUILDS THE ELEMENT CONSISTENT MASS MATRIX

SADX88	CONVERTS UNFORMATTED DATA TO FORMATTED DATA IN FIELDS OF 10, EACH RIGHT JUSTIFIED AND ACCEPTS $COMMENT CARDS IN DATA
SADX89	SOLVES EIGENVALUE PROBLEM |A-ALAMBD*B| X=0
SADX90	SOLVES EIGENVALUE PROBLEM
SADX91	SOLVES EIGENVALUE PROBLEM
SETIME	STARTS EXECUTION TIMER (NONIMSL LIBRARY)
GETIME	STOPS EXECUTION TIMER (NONIMSL LIBRARY)

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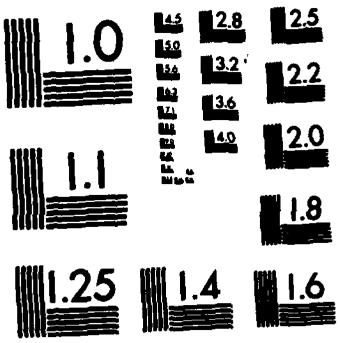
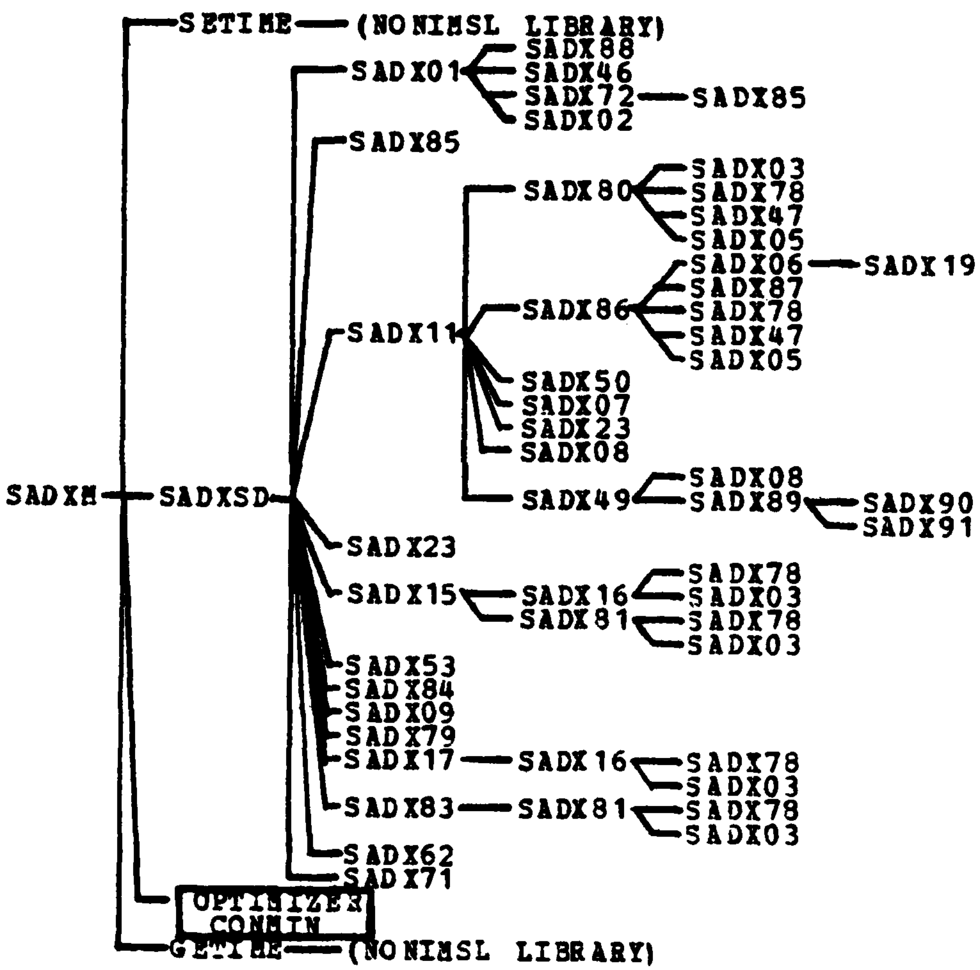


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE XXV

PROGRAM BLOCK DIAGRAM



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